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CORRECTION

MONTHLY WEATHER REVIEW, January, 1927:

Page 8, first column, about halfway down, the equation should be:

$$\frac{\delta u}{\delta z} + o, \frac{\delta v}{\delta z} + o.$$

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MEASUREMENTS OF SOLAR RADIATION AND THEIR INTERPRETATION

BY CHARLES F. MARVIN

[Presidential address delivered before the American Meteorological Society meeting at Philadelphia, December, 1926]

Solar energy in the form of thermal radiation which enters and penetrates the atmosphere of the earth is recognized by all, I believe, as the primary source of all the phenomena of weather, and, indeed, of life itself on our planet.[1] Surely, then, no other subject is more deserving of exhaustive measurement and investigation than solar radiation, especially if we also include the study of sun spots, prominences, and like solar phenomena as other evidences of solar activity.

This address, however, is limited to a very brief consideration of certain sources of error inherent in fundamental measurements of solar radiation and to the interpretation of the observational data.

Systematic study of a scientific question calls first of all for a sound theoretical background and plan of procedure; second, for adequate instrumental apparatus by means of which the third prerequisite of investigation may be secured, namely, a homogeneous body of observational data. The fourth and last stage is a search for the correct interpretation of the observations.

In the case of the solar constant as a question for scientific investigation, it remained for Samuel Pierpont Langley first to transform the imperfect, insufficient older theories of atmospheric transmission and depletion of incoming radiation to the more complete and adequate theoretical background such a problem required. Second, by the invention of the bolograph he finally, for the first time, made it possible to evaluate correctly the atmospheric absorption, and hence the original intensity of the solar radiation as it reaches the outer limits of the earth's atmosphere. This physical magnitude Langley called the solar constant of radiation. Only in later years did he contemplate the possibility that the intensity of solar radiation was a variable.

In the introduction to his report to the Chief Signal Officer on his solar expedition to Mount Whitney in 1880, Langley wrote these significant words:

> If the observation of the amount of heat the sun sends the earth is among the most important and difficult in astronomical physics, it may also be termed the fundamental problem of meteorology, nearly all whose phenomena would become predictable if we knew both the original quantity and kind of this heat; how it affects the constituents of the atmosphere on its passage earthward; how much of it reaches the soil; how, through the aid of the atmosphere, it maintains the surface temperature of this planet; and how, in diminished quantity and altered kind, it is finally returned to outer space.
>
> Meteorologists have till lately occupied themselves more with the secondary effects of this solar radiation than with the considerations just referred to, though this primary study will at least enable us to survey subordinate and familiar phenomena from a more general point of view and will correct some errors.[2]

The Weather Bureau is sometimes reproached for seeming to give investigations of solar radiation as a possible aid to weather forecasting an unsympathetic reception. In this connection it is interesting to note that Langley's solar expedition to Mount Whitney was not only indorsed, but also financed, by the then juvenile Weather Service of the Signal Corps. From 1880 to the present time the meteorologists of the Weather Bureau, although naturally skeptical of unproven claims of solar variability and the direct response of weather to such alleged solar variation, have always retained a keen interest in the ultimate outcome of the remarkable investigations inaugurated by Professor Langley at Mount Whitney and carried forward with such consummate skill and persistence by Dr. Charles Greeley Abbot.

In the beginning of Langley's research he spent more than a score of years upon what we have called the second or instrumentation stage of the extremely difficult investigation necessary before it was possible to reach even the approach to the third stage; that is, the beginning of the collection of systematic observations.

In fact, at the time of his death in February of 1906, Professor Langley had before him only the merest fragment of the observational data now available. Nevertheless, he was impressed with the possibility of appreciable day-to-day variation in the true values of the solar constant. This interpretation of the data then available was plausible enough, because even the best measurements then made at Mount Wilson in the summer of 1905 showed a probable day-to-day variation of nearly 1½ per cent. The variability of far less satisfactory earlier observations made at Washington was still greater. It is now generally believed these large variations were chiefly, if not wholly, caused by the combined sources of variation due to instrumental errors and atmospheric influences.

After another score of years of progress there is available to-day a large body of measurements of the solar constant. Let us examine these carefully in order that the evidence bearing on the question of constancy or variability of the sun may be more clearly understood and the true thermal basis of theoretical meteorology more accurately evaluated.

[1] Fully recognizing the probability that some fluctuations in intensity of solar radiation occurred during geological times, I am reluctant to believe that radiant solar energy alone dominated past climates as it does at the present time, or that solar control will continue to be what it is to-day in the remote future. For the climatologist I must add my conviction that solar heat alone, as we now know it, is not necessarily sufficient to have caused or to explain the climates which geologic history shows the earth has experienced in the past, climates which there are many reasons to believe may recur in like kind in the remote future.

The thesis *of variations in the availability at the earth's surface of the stores of its internal heat* has a claim to be recognized as a possible and at times an important factor in causing the climates of the ages, past and future (see Marsden Manson's "The Evolution of Climates"). Geophysics and isostasy compel us to recognize that what we call the solid crust of the earth is after all of only apple-skin thickness if the earth were reduced to the size of the apple, a crust less than 100 miles thick at the most. The matter within is plastic, or even fluidlike, under slowly acting great forces. Such properties are due to high temperatures as well as great pressures.

It is probably impossible at the present time for anyone to set out a satisfactory and acceptable explanation of the mechanism and process by which earth heat has at any time in the past or may again dominantly influence climatic conditions. Nevertheless, the climatologist can not afford to disregard the cumulative effects on climate over long ages of time of probable variations in the availability at the surface of the internal heat of the earth. The stores of heat seem to be within the crust is relatively very thin, and who can say that slow variations in availability at the surface do not occur?

[2] Professional Papers of the Signal Service, No. XV, p. 11.

41422—27——1

In this age of marvelous advances in scientific measurements it is perfectly easy to recognize that in all probability the sun is a slightly variable star. To state it thus simply, however, is to mislead the general public and even a great many men of science. Suppose I ask one of these the question: "Tell me, now, just how much do you think the sun varied from day to day during the year? The Smithsonian Institution gave the Weather Bureau the values whenever observed, and they were printed on the Washington weather map. How much variation do you think these observations show?" Outside of the experts familiar with these daily values I have not found a single person who could answer my question in any quantitative way. Every one, however, has the mental impression that the variation is appreciable or considerable. I have no doubt there are a number of persons who, if pressed for an answer, would put the amount of day-to-day solar variation at the order of 1 or 2 per cent or more. What are the facts? No one can form an independent appraisal of the facts without a fair acquaintance with the major sources of secular and accidental errors. Let me lay some of these before you.

A least-square computation, based on the good and bad observations during the past 18 months, indiscriminately, shows that *the total probable variation due to all causes*, that is, errors and atmospheric causes of variation combined with solar changes, was *one-third of 1 per cent*. If we reject 42 values graded by the observer as unsatisfactory because observing conditions were poor, the total day-to-day variation becomes less than *one-quarter of 1 per cent*. Analysis of the observations has shown that only a *part* of this total, probably not even half of it, can be ascribed to the sun itself. Is there after all any real evidence that the whole of this small quantity is not the inevitable errors of observation? I hope to throw some light on this question later in the present paper.

It is well known that the pyrheliometer is the ultimate standard of reference in all measurements of solar radiation.

Doctor Abbot has stated this matter forcefully on page 89, Volume IV, of the Annals of the Astrophysical Observatory:

> The basis of our research lies in the exactness and stability of its pyrheliometry. We are watching for changes in the radiation of the sun from day to day and from year to year. In doing so we determine the values of the intensity of solar radiation outside of the atmosphere in calories per square centimeter per minute. The accuracy of the comparison depends, however, primarily on the exact comparability over long intervals of our observations at the earth's surface. As the bolometer (which we are obliged to use in order to determine the transmission of the earth's atmosphere) is not a standard instrument for radiation and gives merely relative values, it is necessary to standardize it against some other instrument. For this purpose we have chosen the pyrheliometer.

How great is the need, then, for the utmost constancy in our pyrheliometry.

In what follows we consider only certain sources of errors unavoidable even in pyrheliometers of the highest type. These seem to me to be of such magnitude in themselves that they help to explain both day-to-day as well as secular changes in the derived values of the solar constant. This is especially the case when the day-to-day variations amount to only a few tenths of 1 per cent of the mean intensity. Only a few of the several standard pyrheliometers in use will be discussed.

Pyrheliometers are *absolute* instruments when their indications can be transformed directly into units of thermal energy of radiation received, without comparison or reference to any other type of instrument. *Secondary* pyrheliometers are those instruments whose indications are in arbitrary units and must be reduced to standard thermal units by comparison with absolute or other standardized instruments.

In the class of absolute instruments we must mention the water-flow and water-stir pyrheliometer of the Astrophysical Observatory of the Smithsonian Institution, the electrical compensation pyrheliometer of Ångström, and the silver disk electrical pyrheliometer used by the Weather Bureau since 1912.[3] All these instruments are subject to an uncertain error due to the amount of radiation exchanged between the sky and the sensitive surfaces within the pyrheliometer, which radiation is added algebraically to the direct radiation from the sun. The instruments also require a greater or less correction for the incomplete absorption of the radiation which is transmitted to the sensitive surfaces for measurement.

The sources of error which we select for consideration arise from the sky radiation admitted to the sensitive surfaces, also from losses due to imperfect absorption by the blackened silver disk or by the walls of the water-flow pyrheliometer.

CHARACTERISTICS OF PYRHELIOMETER VESTIBULES

It is impossible to expose the sensitive element of any pyrheliometer to solar radiation alone. A wide area of sky around the sun also adds its radiation partly or wholly to that from the sun's disk. While the intensity of sky radiation is feeble compared with that from the sun, the sky area in some instances is several hundred times the area of the solar disk. Therefore the feeble sky radiation and its variation can not be disregarded if one attaches great importance to changes of small fractions of 1 per cent in the derived values of the solar constant.

The word *vestibule* refers to that part of the pyrheliometer which delimits the admission of radiation to the sensitive measuring apparatus within. This vestibule serves the purpose of well-known collimating devices. The amount of radiation admitted is defined by an outermost and innermost diaphragm, separated a greater or less distance. Intermediate diaphragms are also required, whose function is to cut off interval reflections in the vestibule and to reduce air circulation as much as possible. Figure 1 illustrates diagrammatically the critical elements of the vestibules of certain standard pyrheliometers indicated.

The apparent semidiameter of the sun is slightly more than half a degree. On this account the vestibule of the pyrheliometer must be made to flare to the extent of at least a whole degree or more to allow for imperfect pointing of the vestibule at the sun and for errors in following the solar motion. This flare is provided by making the outer diaphragm a small amount larger than the inner one, but while the vestibule thus arranged admits all the radiation from the full disk of the sun, nevertheless sky radiation from a relatively large area is also admitted.

Before passing to the detailed analysis of the geometric relations, it may be mentioned that the vestibule of the standard type of silver disk pyrheliometer used by the Smithsonian Institution at all its stations prior to 1925 admitted a comparatively wide angle of sky radiation. Since the older type has been used for all observations published prior to 1927 and upon which have been based the claims of solar variability, methods of weather forecasting dependent upon the supposed

[3] Annals of the Astrophysical Observatory, Vols. III and IV; also MONTHLY WEATHER REVIEW 47:708, and 52:302.

variability, etc., it is necessary that we discuss the characteristics of the vestibule of this and other instruments in order to appreciate the difficulties which arise when we try to interpret solar constant values as published. It was probably because of certain anomalous results mentioned hereafter, arising from analysis of the Harqua Hala and Montezuma observations, that action was taken in the latter part of 1925 to lengthen the

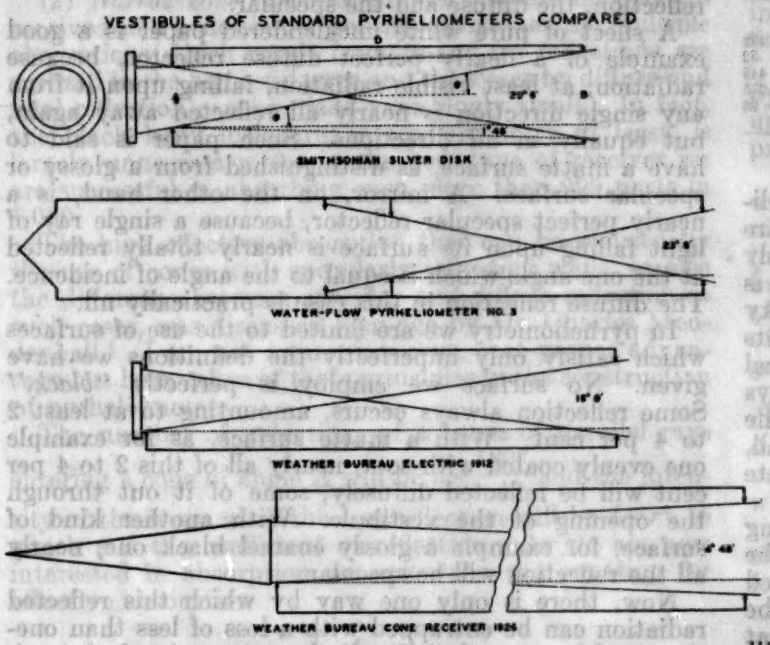
VESTIBULES OF STANDARD PYRHELIOMETERS COMPARED
SMITHSONIAN SILVER DISK
WATER-FLOW PYRHELIOMETER NO. 3
WEATHER BUREAU ELECTRIC 1912
WEATHER BUREAU CONE RECEIVER 1926

FIG. 1.—Vestibules compared and the geometric angular aperture formulated

vestibules of the silver disk pyrheliometer from about 7 to 30 inches, thereby reducing the sky area to about 5.5°.

Analysis of vestibules.—If we call the diameter of the inner diaphragm of the vestibule A, the diameter of the outer diaphragm B, and the distance between the diaphragms D, it is easy to see from the construction lines of the vestibule of the silver disk pyrheliometer in Figure 1 that θ, the half angle of the aperture of the vestibule, is found from the equation $\tan \theta = \frac{A+B}{2D}$.

There is some difference of view as to how the angular aperture of any particular vestibule should be calculated. It is true that no single point of the sensitive surface receives radiation from the entire sky area. Nevertheless, all that solar and sky radiation which passes through the vestibule of the pyrheliometer must impinge somewhere upon the sensitive surface and exert its influence upon the measurements. In a recent discussion of this question Doctor Abbot demonstrated that the effective area equivalent to the geometric angle given above is approximately the angle given by the expression $\tan \theta = \frac{B}{D}$, which is about half the geometric angle and is the appropriate angle to use in evaluating the effects of sky exposure of different pyrheliometers. If, as in some pyrheliometers, notably the Ångström, the sensitive surfaces do not intercept all the solar and sky radiation which passes through the vestibule, then the incoming radiation which passes by the edges of the receiver is entrapped within the inclosure, and the general effects thus produced upon the measurements are likely to be more harmful than if all the radiation had been intercepted.

Figure 2 is a graphic picture of what the myriad of points on the receiving surface of various pyrheliometers "see" when the instrument is pointed centrally toward the sun.

The detailed analysis of conditions in the case of the well-known silver disk pyrheliometer is shown in the upper left-hand corner of the diagram by the large circle whose outer limit represents the outermost points of visible sky from which radiation can pass through the vestibule of the instrument. The sun's disk, drawn to the same scale, will occupy a tiny area in the center of the outer circle.

The vestibule of this instrument admits a solid cone of radiation having a geometric aperture of 20° 6′ = 1,206 minutes of arc. The solar disk subtends an angle of about 32.6′ of arc. The total area of the sky which radiates to the receiver is, therefore, one thousand three hundred eighty-six times the area of the solar disk.

A single point at the center of the silver disk sees only the sky radiation within the circle $c\ c\ c$ with the sun exactly in its center, assuming the instrument to be pointed centrally at the sun. This circle subtends an angle of 10° 38′. Points on the disk which are eccentric in position see about the same angular area, but this is composed partly of other portions of the sky than those seen from the central point, and the sun is eccentric therein as indicated by the circle x.

The sun and sky areas as seen by one or more points near the extreme edge of the illuminated portion of the disk are represented by circles such as $y\ y\ y$, etc. In these circles the sun is just within the edge on one side of each circle. If the disk or receiving surfaces are some distance behind the innermost diaphragm, there will be quite an appreciable annular ring of penumbra and diffraction effects just outside of the fully illuminated central portion of the disk.

In receivers of the black body type, like the water-flow pyrheliometer, many sensitive portions of the surface are located quite a distance behind and outside of the

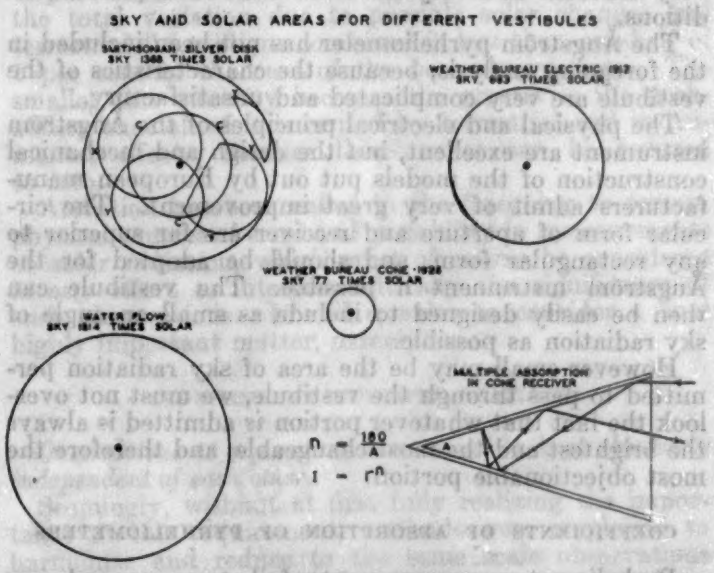
SKY AND SOLAR AREAS FOR DIFFERENT VESTIBULES
SMITHSONIAN SILVER DISK
SKY 1368 TIMES SOLAR
WEATHER BUREAU ELECTRIC 1912
SKY 983 TIMES SOLAR
WEATHER BUREAU CONE 1926
SKY 77 TIMES SOLAR
WATER FLOW
SKY 1814 TIMES SOLAR
MULTIPLE ABSORPTION IN CONE RECEIVER

FIG. 2.—Relative geometric areas of sun and sky whose radiations pass through the vestibules of various pyrheliometers

innermost diaphragm of the vestibule. Therefore, portions of the sensitive surfaces will receive radiation from sky areas within which the solar disk does not appear at all. One edge of these circles lies near the sun and extends from it to the outer limits of the whole sky zone admitted. In a very slight degree this condition is true with each of the disk instruments, but is least so when the disk is near the innermost diaphragm of the vestibule.

The vestibule characteristics of the pyrheliometers shown in figures 1 and 2 are tabulated below:

Table of approximate characteristics of vestibules of pyrheliometers

Instrument	A	B	D	Angle θ $\tan\theta=\frac{B}{D}$	Ratio of sky solar disk
	Inches	*Inches*	*Inches*	° ′	
Smithsonian Silver Disk	1.020	1.461	7	11 42	492
Smithsonian Vestibule, 1925	1.024	1.850	30	3 50	52
Smithsonian Water Flow, No. 3 [1]	.906	1.142	5	11 10	449
Weather Bureau Electric, 1912	1.475	1.775	11.56	8 44	275
Weather Bureau Cone Receiver, 1926	.700	1.120	24.2	2 40	26

[1] Corrected for reflecting surfaces inside.

Let us now suppose that two or more of the pyrheliometers whose characteristics we have analyzed are undergoing comparison by being pointed simultaneously at the same sun. In an extreme case one instrument is registering radiation from nearly 20 times as much sky area as the other, and in any case the two instruments are not, strictly speaking, measuring the same physical quantity. If comparisons are made on different days the differences between the quantities measured by the instruments will differ. These amounts may be small, but they can not be disregarded when an ultimate accuracy of a few tenths of 1 per cent is required.

The quantitative amount of sky radiation passing through the vestibules of different instruments can be estimated in some cases from studies like those carried out by Doctor Kimball. These amounts may indeed be quite negligible at stations in very arid regions and at high altitudes overlain with nearly dust-free air. Nevertheless, the general practice has been to compare the secondary pyrheliometers used in the daily work with ultimate standards at some base station located under very different and very far from ideal atmospheric conditions.

The Ångström pyrheliometer has not been included in the foregoing analysis, because the characteristics of the vestibule are very complicated and unsatisfactory.

The physical and electrical principles of the Ångström instrument are excellent, but the design and mechanical construction of the models put out by European manufacturers admit of very great improvement. The circular form of aperture and receiver are far superior to any rectangular form, and should be adopted for the Ångström instrument if possible. The vestibule can then be easily designed to include as small an angle of sky radiation as possible.

However small may be the area of sky radiation permitted to pass through the vestibule, we must not overlook the fact that whatever portion *is* admitted is always the brightest and the most changeable, and therefore the most objectionable portion.

COEFFICIENTS OF ABSORPTION OF PYRHELIOMETERS

Pyrheliometer measurements fail to command our entire confidence, because we know that in general the sensitive surfaces do not absorb more than 96 to 98 per cent of the total radiation which passes through the vestibule. Here again secular and accidental changes in small losses due to this cause must be duly considered when we are striving for an accuracy and constancy of measurement of a few tenths of 1 per cent.

In order that we may clearly follow a short analysis of the "lack of blackness" of the receiving surfaces of pyrheliometers, we must have in mind the exact meaning of certain words we use.

A surface is perfectly black, as this word is here used, only when it absorbs all the radiation which impinges upon it at any angle. Unfortunately no such surface is available. The surfaces we are compelled to use are, therefore, to be thought of as partial, that is, imperfect or poor, reflectors. We must now think of two kinds of reflection, the diffuse and the specular.

A sheet of pure white uncalendered paper is a good example of a nearly perfect diffuse reflector, because radiation, at least visible radiation, falling upon it from any single direction is nearly all reflected away again, but equally in *all* directions. Such paper is said to have a matte surface, as distinguished from a glossy or specular surface. A mirror, on the other hand, is a nearly perfect specular reflector, because a single ray of light falling upon its surface is nearly totally reflected at the one angle which is equal to the angle of incidence. The diffuse reflection in this case is practically nil.

In pyrheliometry we are limited to the use of surfaces which satisfy only imperfectly the definitions we have given. No surface we employ is perfectly "*black*." Some reflection always occurs, amounting to at least 2 to 4 per cent. With a matte surface, as for example one evenly coated with soot, nearly all of this 2 to 4 per cent will be reflected diffusely, some of it out through the opening of the vestibule. With another kind of surface, for example a glossy enamel black one, nearly all the reflection will be specular.

Now, there is only one way by which this reflected radiation can be entrapped with a loss of less than one-thousandth part of the radiation transmitted through the vestibule. This requires that the absorbing surfaces be not diffuse reflectors, as in all ordinary practice, but specular reflectors, for the reasons explained in what follows.

(1) *The "black body."*—A hollow chamber with a blackened interior and a vestibule upon one side for admission of radiation is widely known as a "black body." The use of this in pyrheliometry is exemplified by Doctor Abbot's waterflow pyrheliometer, whose vestibule characteristics we have already analyzed.

The widespread general assumption is that any "black body box" absorbs practically 100 per cent of incoming radiation. This assumption, however, is partly fallacious, and calls for the correction brought out in the following analysis.

The mistake arises from not taking proper account of the difference between specular and diffuse reflection, and also because the universal practice seems to be simply to blacken the inner walls of the chamber dead black with lampblack mixed in alcohol, with a little shellac added to cause the lampblack to stick. These are the standard instructions for producing matte black surfaces.

The prevalent impression is that the solar and sky radiations which have passed through the vestibule of the black body, if not absorbed at first incidence, will be reflected to and fro within the chamber and will be at length almost completely absorbed somewhere upon the walls.

Disregarding the sky radiation as a negligible factor in the present connection, let us say that of the whole solar beam, wherever it falls within the blackened chamber, 96 per cent is at once absorbed on the first incidence. As the walls are matte surfaces, 4 per cent of the solar beam will be diffusely reflected from every point, and a part of

this will at once pass right out through the vestibule; there is no chance for it to be reflected to and fro. Of course, not all of the reflected 4 per cent can pass out through the vestibule, but the loss is appreciable and can not be disregarded. The result is quite different if the inner walls are blackened with a thin, glossy, black enamel which *reflects specularly*. The effects are best exemplified in the cone receivers, which will now be discussed.

(2) *Narrow cone receivers.*—If the whole solar beam is received in a cone-shaped sensitive chamber the multiple absorptions which result from to-and-fro reflections are realized in the highest degree and the losses by diffuse and final reflection can be made vanishingly small. In fact, the black body inclosure, in pyrheliometry at least, is largely unnecessary, for in the new type of receiver we are successful in absorbing even more than 999 parts in 1,000.

The high effective absorption that can be realized by the use of cones with specularly reflecting walls, as also the difference between specular and diffuse reflection in such cases, was discussed long ago by Dr. Charles Mendenhall.[4] I am not aware, however, that proper advantage has been taken of these principles in the construction of pyrheliometers.

The number of reflections of a beam of parallel rays entering a cone of angle A will be $n=\frac{180^\circ}{A}$ and the intensity of the beam after the last reflection will be $I=r^n$, in which r is the coefficient of reflection. As we are now interested in absorption we can write the equation for effective absorption

$$A=1-r^n.$$

This equation gives the effective absorption on the basis that the coefficient r is pure specular reflection and that the matte reflection is zero. Some matte reflection is inevitable. Any diffuse reflection will tend to nullify the advantages of the multiple reflections. The ultimate result is to set a limit upon the narrowness of the cone we need to choose in order to realize the maximum attainable effective absorption.

The physical data upon which this question can be settled for the kinds of surfaces we must use are not now available. but the Weather Bureau is planning, with the cooperation of the Bureau of Standards, to secure the necessary observations.

The ultimate standard of all solar constant values up to the present time rests upon a considerable number of intercomparisons of various silver disk pyrheliometers with duplicate standard water-flow pyrheliometers of the kind we have mentioned. Intercomparisons were made in Washington and at Mount Wilson.

In addition to the known unsatisfactory sky conditions at Washington, the 40 comparisons made there were in a beam of reflected radiation and the losses due to reflection had to be evaluated by a separate set of pyrheliometer readings, thus increasing the sources of error and variability.

The 32 comparisons at Mount Wilson were made under better sky conditions and in a direct solar beam followed by means of an equatorial mounting. The 72 observations were discussed in six groups. Of the results Doctor Abbot writes:

> The maximum divergence of the mean results of these groups is 1 per cent. Hence it is believed that the mean result of all the comparisons made under such diverse circumstances must be within 0.5 per cent of the truth. The probable error is 0.1 per cent. It is believed that this standard scale is reproducible by the secondary pyrheliometers with the adopted constants given to within 0.5 per cent. The divergence of this scale from that of Ångström appears to be 3.9 per cent.

Ångström in October, 1919, fixed his value at 3.23 per cent lower than Abbot's.[5]

The unexplained divergence of 3 to 4 per cent between the normal pyrheliometers by Abbot and Ångström indicates that further research is necessary before a final definitive standard instrument is realized.

These citations refer to the outstanding errors of the pyrheliometer as an absolute instrument, and depend upon the mean results of a considerable number of comparative readings.

Our chief concern in this analysis, however, is not with the mean error of large groups but with the magnitude of the probable changes of scale of any given instrument in its daily use, due to variations of sky brightness, secular changes incident to age, changes of absorption, occasional changes of instruments, changes of observers, etc. These fluctuations are necessarily greater than the fluctuations of group means.

It must be remembered also that before we get a derived value of the solar constant for any particular day there must be added to the foregoing causes of variation all those entailed by the use of the bolograph, which include empirical corrections for losses of radiation at the reflecting surfaces of mirrors, prism absorptions both partial and complete, the empirical factors for interpretation of pyranometer readings, and other entirely terrestrial causes of fluctuations in the final values of the solar constant.

Changes in the final derived values of the solar constant, due to all the foregoing causes, must certainly exist and obviously should not be ascribed to solar origin, especially when very careful statistical analysis of past observations over a number of years shows that the total variation due to possible solar changes and terrestrial fluctuations combined is less than one-half of 1 per cent in the case of the best observations. The smaller this quantity becomes the greater is the probability that all of it is caused by terrestrial and instrumental effects, because these never can be reduced to zero.

Attention has been called in the foregoing to certain physical sources of error and variability in measurements of solar radiation, which must of course be considered in any effort to interpret critically the significance of such observations. It still remains to consider a final highly important matter, namely:

INDEPENDENT MULTIPLE STATIONS

Observations at separate stations must be kept absolutely independent of each other.

Seemingly, without at first fully realizing the importance of this requirement, methods were employed to harmonize and reduce to the same scale observations made at approximately the same time at separate stations. However, the result proved so unsatisfactory that a new computation and reduction of the entire body of original observations was undertaken. The difficulty is easily understood, for this is a question of statistical relationship, hence adjustments of individual observations from separate stations by intercomparisons necessarily tends to introduce artificial correlation between them.

[4] Mendenhall, C. E., On the Emissive Power of Wedge-shaped Cavities and Their Use in Temperature Measurements. Astrophys. Jour., vol. 33, No. 2, March, 1911.

[5] Annals Astrophysical Observatory, vol. 3, p. 72, MONTHLY WEATHER REVIEW November, 1919, 47: 790.

All methods thus far devised for deriving a value of the solar constant from fundamental observations inherently introduce errors peculiar to the particular station, its instrumental equipment, the daily atmospheric condition, and the seasonal march of the weather elements. That these influences operate is shown by the well-known correlation between solar constant values and the atmospheric transmission, which is, for well-known reasons, nearly always considerable and negative, whereas it should be zero. A climatic effect of a 12-month period, also found where none should appear, is further proof of the presence of the errors mentioned.

If it is ever to be possible to evaluate these instrumental and terrestrial causes of fluctuation and to disentangle from them possible solar changes, multiple station reports must be separately reduced and published as independent values. Inherent errors, certain to be present, can be satisfactorily evaluated and eliminated, if at all, only by analyzing a long series of such independent observations.

A rigorous scientific procedure would seem to require that the observations at wholly independent stations shall be reduced by methods and by the application of corrections, coefficients, factors, etc., *based upon purely physical observations at the one station*, just as if no other station in the world existed.

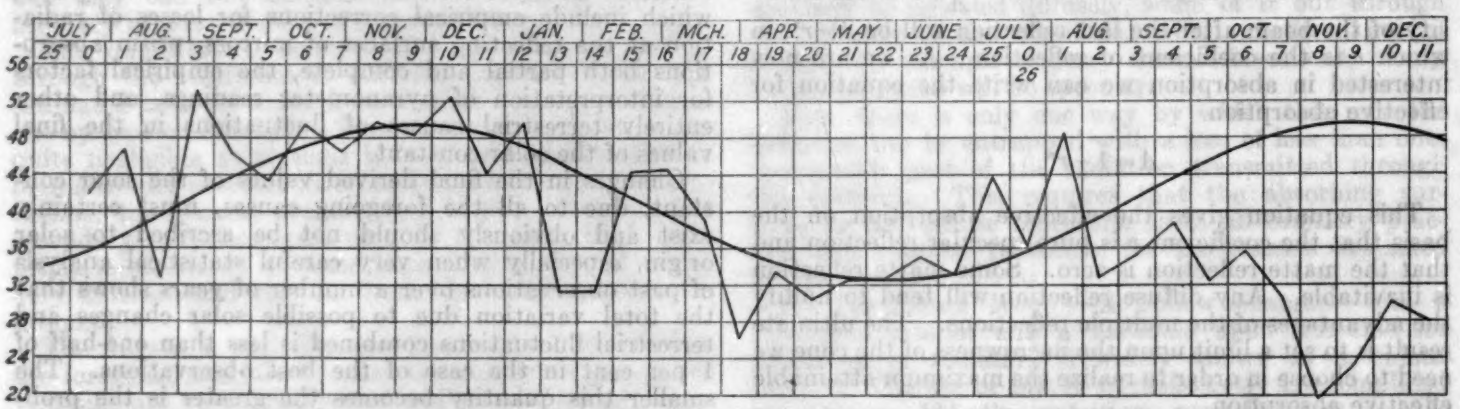

FIG. 3.—Fourteen-day mean values of provisional solar constants as published from July, 1925, to December, 1926. Smooth curve is the seasonal or 12-month period (a terrestrial effect) deduced from five years of earlier observations. Nearly all the 14-day mean values could have been forecast from this seasonal curve with few failures and more than a year in advance. The values for October, November, and December are conspicuously discordant.

Inconsistencies between independent stations must be expected in the present stage of the art, and may well be regarded as a mark of the independent origin of the data. We need to know the magnitude of the discrepancies which would be disclosed by bringing together the derived values of the solar constants from several stations whose observations are truly independent of one another.

The investigator wants the fundamental original observations. The pyrheliometer readings and the bolographic solar constant secured by the pure Langley method, and wholly independent of measurements made at any other station, are the real original observations.

INTERPRETATION OF OBSERVATIONS

So much has been published in this Review[6] on the analysis of solar constant values that only the major conclusions need be summarized here.

Day to day or short period variability.—Critical examination of all observations published up to November of 1924 indicates:

(1) The total variability of solar constant values from a single high-grade station is well under one-half of 1 per cent. If not all of this is of terrestrial origin, the solar part can be evaluated only by a least square analysis of comparable observations from two or more stations.

(2) All observations consistently show a well-defined climatic effect in the form of a 12-month period.

(3) The annual periodicity in the latest Montezuma values is verified by the fit of these values to the 5-year smooth normal curve as shown in Figure 3. The zigzag line connects 14-day mean values of solar constants from July 16, 1925, to December, 1926. These are the latest values published. With the exception of the values for October, November, and December, 1926, the conformity to the seasonal period deduced from the 5-year means is striking. For some unknown reason the low October, November, and December values are inconsistent, not alone with corresponding values for the preceding six years, but with the view that we should expect high values of the solar constant at the present time of sun-spot maximum.

Long period or secular changes.—Data for the analysis of slow, progressive changes over years, sun-spot periods, etc., as yet are very meager.

The observations at Mount Wilson from 1905 to 1920 were made only during summer months. Two sets of values were derived from the same original parent observations, which latter represent the results derived by the rigorous Langley method and are hereinafter designated E_0. The second set is obtained from the first by the application of a water vapor correction, and are hereinafter designated E_0'.

Assuming now that all derived values fluctuate from day to day, due to combined solar and terrestrial causes, it is plain that any correction for terrestrial errors will be valid only when it reduces the total variability of the parent data.

Since the corrected data show the same variability as the parent data, they can not claim to be superior. More conclusive proof of the inferiority of the corrected values is shown by the amplitude of the 12-month period in the corrected data, which is nearly double that in the parent data. The amplitude would probably be nearly zero if the values were true solar constants.

Of the parent data published for Mount Wilson (E_0) and the corrected values (E_0'), the latter are the only values used in discussions by both Doctor Abbot and Mr. Clayton, notwithstanding that the internal evidence cited above indicates that the errors are probably least for the pure bolographic values.

Whether we include or exclude the observations known to be impaired by Katmai dust in 1912 and 1913, the true mean solar constant from all observations at Mount

[6] MONTHLY WEATHER REVIEW, 1925, 53: July, 285-306; August, 343-348; December, 519-528.

Wilson is $E_0 = 1.912$, and the $E_0' = 1.933$, which latter is artificially in excess of the former by 1.1 per cent. These mean values are both derived by the harmonic analysis. which is the best, if not the only, way to compute a true mean of a periodic function when values for part of the cycle are missing, and are therefore probably the strongest and most definitive values which can be drawn from the Mount Wilson work.

It was not known at the time observations began at Calama on July 27, 1918, that the past as well as the future values of the solar constant would exhibit the seasonal feature of a 12-month period. Moreover, little consideration seems to have been given to the important prerequisite that values at separate stations must be kept wholly independent.

What is found in the published results is that the pure bolographic values at Calama under winter conditions began in close agreement with the high summer values, E_0', at Mount Wilson. If the values at both stations were influenced by no other error than the annual periodicity, then it must follow that the simultaneous summer and winter values in the two hemispheres should differ by the sum of the amplitudes of the two periodicities, because later computations proved these periods to be in opposite phase relations with a maximum difference of about 0.016 calories, or 0.8 per cent. The agreement between the summer values at the two stations seems therefore to indicate that the Southern Hemisphere observations started upon a scale in accord with the E_0' values at Mount Wilson, which were then regarded as the most dependable.

This condition had the very harmful effect of starting the observations at the Southern Hemisphere station upon a scale of values which was too high, first because the summer and fall values at Mount Wilson were running near the maximum phase, due to the annual period with a large amplitude; second, because the E'_0 values are themselves probably a full 1 per cent too high, due to the application of a water vapor correction of doubtful validity.

The writer is compelled to emphasize the doubtful accuracy of the high values of the pure bolographic observations as published for Calama and Montezuma up to January, 1922. It is very doubtful, indeed, in the writer's mind, at least, whether absolutely independent pure bolographic observations would ever have given these high values had the station at Mount Wilson never existed.

There is no physical basis by which an artificial scale can be preserved. When the station at Mount Wilson was discontinued in favor of a new station at Harqua Hala, and the station at Calama was moved to Montezuma in 1920, the latter became and still remains the primary observatory. In the course of a year or two thereafter direct physical verification of the mirror, prism, and other corrections at the station would have to be made in order to maintain the accuracy of the instrumental constants and corrections required by the pure bolographic method. Thus the values at Montezuma would tend to revert to the magnitude of values at a wholly independent station—that is, to a scale similar to the original pure bolographic values, E_0, at Mount Wilson when that station was a wholly independent one.

The writer, unfortunately, has not had access to original data and observations by which to establish the correctness of the deductions stated above, but we do know that the published solar constants fell off in 1922 to unprecedented low values, which have averaged closely the same up to the present time. These values were only apparently low. They could not be explained in relation to the former high values, E'_0, except to misinterpret them as evidence of a marked decline in solar radiation. The fact is, these low values agree very well with the former pure bolographic values, E_0, obtained at Mount Wilson, whose average was 1.912.

It is plain from the adjustments described above that artificial changes run through the solar constant values since 1918. Moreover, the final values are not yet available, since many of the observations are now undergoing recomputation. This will doubtless produce some homogeneity, but it is not obvious how it will ever be possible to eliminate from past observations the correlations due to intercomparisons between nonindependent stations.

CONCLUSIONS

Langley's pure bolographic process for evaluating the transmission losses of radiation in the earth's atmosphere still stands alone and supreme, provided the observations at any one station are reckoned in a manner that makes them completely independent of those at any other station.

Nevertheless, while frequent daily observations by the full Langley or long method furnishes very valuable data, these are now no longer required for the pursuit of practical investigations in solar and terrestrial relationships. For reasons already given by me,[7] pyrheliometer readings alone at high-grade stations serve nearly all purposes, especially if supplemented by simple meterological observations, all of which are very easily made.

What meteorologists and other investigators need is simply the prompt release of the original basic observations. These are not subject to any change except for occasional *errata* or possible material deterioration in instrumental constants. We are glad to point out that a step in the desired direction was taken in 1926 when the Smithsonian Institution arranged for the advance publication by the Weather Bureau of the Montezuma Pyrheliometry, 1920–1926.[8]

There are still needed, however, similar and additional prompt reports from all existing stations. The writer has proposed that arrangements be made for the prompt publication of some such original observations from each station, as follows:

(*a*) Pyrheliometer observations whenever possible at three or more different air masses.

(*b*) Psychrometer readings or equivalent measures of local humidity, including air pressure and state of sky with respect to haze, clouds, etc.

(*c*) Some evaluation from one or more bolograms of the area, or other quantitative measure in comparable units, of the major water vapor absorption bands in the solar spectrum.

It is earnestly hoped some such program of prompt publication of actual original observations may soon be realized.

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[7] MONTHLY WEATHER REVIEW, July, 1925, p. 290, Caption II.
[8] Supplement No. 27, MONTHLY WEATHER REVIEW, 1926.

METEOROLOGICAL FACTORS IN THE QUARTZ CREEK FOREST FIRE

By H. T. GISBORNE

[Northern Rocky Mountain Forest Experiment Station]

It is not often that a large forest fire occurs conveniently near a weather station specially equipped for measuring forest-fire weather. The 18,000-acre Quartz Creek fire on the Kaniksu National Forest during the summer of 1926 was close enough to the Priest River Experimental Forest of the Northern Rocky Mountain Forest Experiment Station for the roar of the flames to bring the residents to their doors several times; so close that hose and gasoline-powered pumps were installed to protect the buildings; so close that the women and children were sent away to greater safety during the most threatening period. Hence the weather records at the station may indicate some of the reasons for the great spread of this fire.

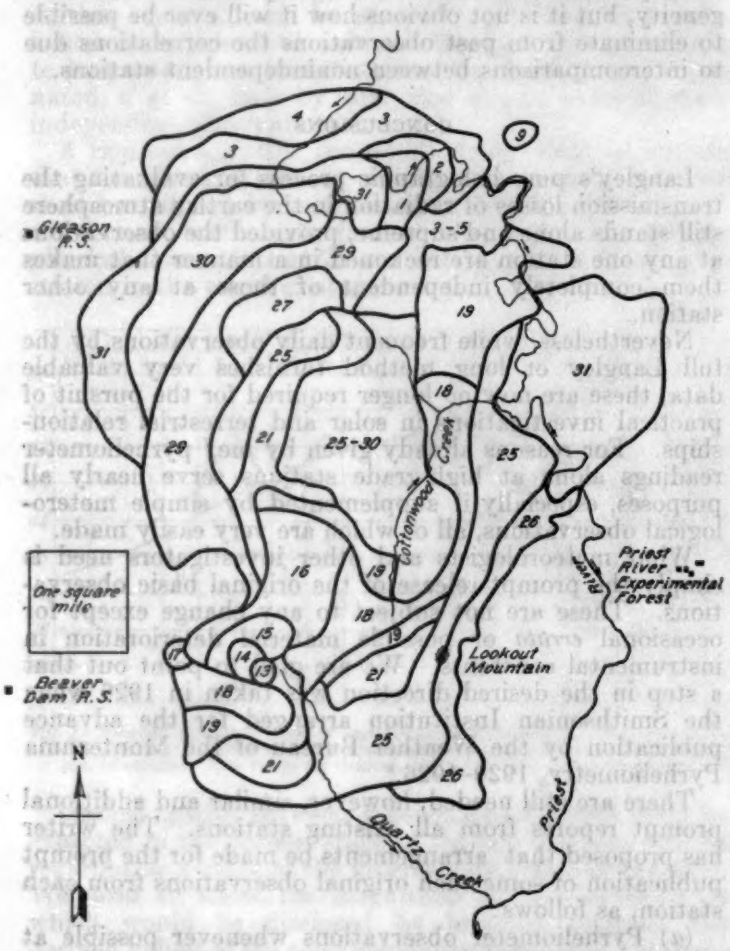

FIG. 1.—Approximate boundaries of burned areas at the close of each day, Quartz Creek fire.

Figure 1 is a map of the burned area, the heavy lines indicating the boundary of the fire as well as it could be determined at the end of each day. The location of the experiment station buildings and the weather-measuring instruments are indicated near the center of the right-hand edge of the map.

The meteorological equipment at this station includes maximum and minimum thermometers, automatic tipping-bucket rain gage, anemometer, two-magnet register, thermograph, hygrograph, and barograph. Regular measurements are made twice daily of the amount of moisture in the forest duff and in dead branch wood.

This fire in the Quartz Creek drainage started during the early morning of July 13, 1926, being one of the 150 or more forest fires set by lightning storms on July 12 and 13, on the 600,000-acre Kaniksu National Forest. It was discovered and located by the lookouts at 2 p. m. of the 13th. When the first three men reached it two and one-half hours later about 20 acres of timber were ablaze and the fire was already flaring in the crowns of single trees and groups of trees, as well as running rapidly on the ground.

Thirty additional fire fighters were called for immediatly, but, because of the demand created by several hundred other fires in northern Idaho and western Montana, only 12 men came. Further reinforcements were entirely insufficient during the following four days. This lack of men at the start, together with the highly inflammable condition of the fuel, put the fire at the mercy of subsequent weather. The immediate cost and loss to the Federal Government and to the private timberland owners and companies are approximated at $274,000, exclusive of the salvage value of the timber burned.

As indicated by Figure 2, the weather just previous to July 12 had been favorable for extreme inflammability of the forest materials. Rapid evaporation, occasioned by high temperature, high wind, and low relative humidity, had dried out the litter and duff to a moisture content of only 7% on a completely cut-over and fully-exposed area by 5 p. m. July 12. Samples of dead branch wood, 2 inches in diameter, showed the same moisture content. As both these materials retain at least 2 per cent moisture until subjected to sustained temperatures of over 100° F. and relative humidities of less than 10%, it is apparent that at least two of the important forest fire fuels were extremely inflammable. Obviously, the stage was set for a true conflagration.

Rain, usual with electrical storms in this region, amounted to only 0.04 inch with a storm on July 13. It fell between 1:45 and 2:45 a. m. At 8:30 a. m., under full timber canopy in the forest, this light sprinkle had moistened the duff to only 19%, and on clear-cut areas to 36%. The remainder of the day was hot, dry, and windy, and by 5 p. m. the duff moisture in the forest was only 9%, and in the open 6½%. The benefits of the rain were short lived indeed. Not another trace fell until August 16, seven days after this fire was completely controlled; hence the remainder of the story, in so far as the weather is concerned, is largely one of temperature, humidity, and wind.

Investigators have tried various methods to determine the cause-and-effect relationships between the weather elements and the behavior of fires. In some cases they have related the final area of the fire to the maximum temperature, the minimum relative humidity, and the average wind velocity of the day when the fire started. In other cases the maximum temperature, minimum humidity, and daily wind movement have each been averaged for the period of the fire and these averages taken to indicate conditions productive of the total area burned by that fire. A more sensitive method would be to compare the maximum, minimum, and mean temperatures, humidities, and wind velocities for the days when the fire made its biggest runs, with the weather conditions on the other days when the fire was spreading least rapidly.

Such a method encounters a great difficulty, however, in the lack of accurate information concerning the size of the fire at the end of each day. Only rarely and through special effort can maps be made to show the fire front locations day by day, and even those have an error which must be assumed as considerable because the maps are necessarily based on hasty observations along a fire front perhaps 15 or 20 miles in length, these being harmonized as well as possible in the circumstances. It is also desirable to distinguish the trenched and controlled front from the untrenched or uncontrolled, in order to follow accurately the growth of the fire each day. Maps prepared by the airplane observers might be of considerable assistance in this respect, but a big and very active fire sometimes prevents close scrutiny even from an airplane.

Choice of a unit for measuring change of size of the fire offers a second difficulty. The area burned over and the length of the fire front are the two most usable units, but both have obvious disadvantages. It would seem that either one should be satisfactory, but as can be seen from Figures 1 and 3, the Quartz Creek fire increased from 8,000 acres on July 25 to 13,600 acres on July 30, yet its perimeter was decreased from 27 miles to 25 miles by that very growth, through the burning out of holes or pockets in the fire so that its exterior boundary was reduced nearer to circular form. It is rather startling to think that a fire can increase 5,600 acres in area, yet have two miles less perimeter as a result. The fact that this did occur indicates, among other things, the need for careful consideration before deciding whether area or perimeter should be used as a criterion of the effects of the weather elements.

Another very important factor influencing growth and ultimate size of the fire is the opposition to spread offered by the fire-fighting organization. This opposition is somewhat independent of the weather. If maps were available showing the location and length of held line—or suppressed fire front—each evening, as distinct from the location and length of the uncontrolled fire front, it might be possible, by isolating this factor to some extent, to determine more accurately the effects of the weather alone on the fire's growth. Unfortunately such a refined map is not obtainable for the Quartz Creek fire, and can not be obtained for very many fires because of the great difficulty involved. Study of a fire has to be incidental to the main job since frequently the man making the study will be forced to drop his observations and help where he can on the fire line. The few observations obtainable aid, nevertheless, in explaining some of the cause-and-effect relationships exhibited by the fire.

In such investigations it is usually good practice to consider first the variations of the effect and then to determine which of their probable causes were most important. One of the major peculiarities of the Quartz Creek fire was its direction of spread. As shown by Figure 1, 87% of the area burned lies north of the point of origin of the fire and 57% northeast of it. As the bulk of these areas is at approximately the same or even a lower elevation than the source, it is obvious that this great spread can not be charged to greater ease of spread of fire uphill or to topography. As the fuels were no more favorable to the north than to the south, the very uneven spread likewise was not due to timber or fuel types. As temperature and humidity undoubtedly were similar throughout the area, the uneven spread can not have been due to these factors. Most of the suppression work of the first few days was concentrated on the south side of the fire, but the northward-spreading head was not neglected.

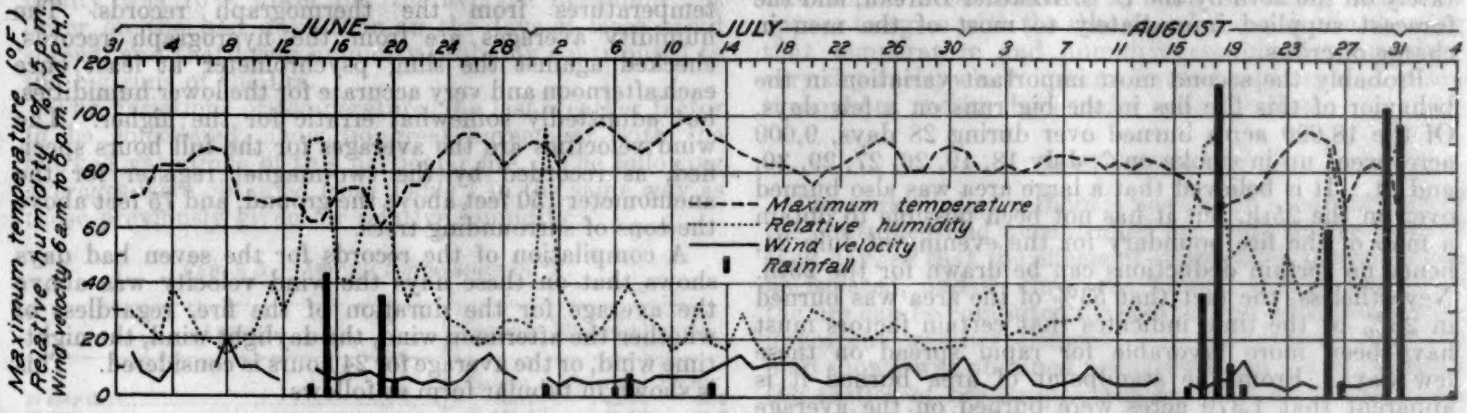

FIG. 2.—March of certain weather elements at the Priest River Experimental Forest, May 31–August 4, 1926

There remains, of the atmospheric elements affecting spread, the wind. The records at the experiment station forest show that the wind was southwest 22 days out of the 28 during which this fire burned. The wind blew toward the northeast 79% of the time; and, as stated above, from 57% to 87% of the area burned was northeast and north of the point of origin. One effect of wind is obvious: As the fire was stopped only 5 miles south of the point of origin, but about 21 miles north of it the

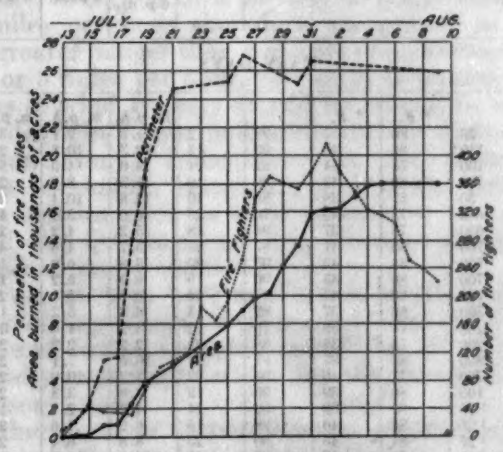

FIG. 3.—Daily changes of area, perimeter and number of fire fighters during the Quartz Creek fire

very great importance of wind direction in the spread of a fire over ground of moderate relief is indicated.

The southward spread of this fire was mostly uphill; therefore the exact effect of the wind upon it is difficult to determine. It is worth noting, however, that on July 21 when there were two marked runs to the south and one to the north, the wind was from the north. It is clear that the direction of the prevailing wind (from the southwest in this region) is very significant, as are also the daily shifts of wind direction. In the case of this fire the northerly winds of July 21 were predicted accurately on the 20th by the U. S. Weather Bureau, and the forecast supplied immediately to most of the men in charge of crews.

Probably the second most important variation in the behavior of this fire lies in the big runs on a few days. Of the 18,000 acres burned over during 28 days, 9,600 acres went up in smoke on 7, July 18, 19, 26, 27, 29, 30, and 31. It is believed that a large area was also burned over on the 25th, but it has not been possible to obtain a map of the fire boundary for the evening of July 24, hence no certain deductions can be drawn for the 25th. Nevertheless, the fact that 53% of the area was burned in 25% of the time indicates that certain factors must have been more favorable for rapid spread on these few days. From the standpoint of area burned it is apparent that 1,370 acres were burned on the average bad day and only 400 acres on the average of the other days. It might be profitable to find out how the weather on these bad days differed from that on the others.

The weather records obtained at the experimental forest, less than two miles from the edge of the fire, show the conditions for each day (Table 1).

TABLE 1

Days		Area burned, acres	Temperature		Relative humidity		Average wind velocity			
			Maximum	Minimum	Maximum	Minimum	Afternoon, noon–6 p. m.	Day, 6 a. m.–6 p. m.	Night, 6 p. m.–6 a. m.	24-hour average, 6 p. m.–6 p. m.
			EASY DAYS							
			° F.	° F.			m. p. h.	m. p. h.	m. p. h.	m. p. h.
July	13	20	90	57	98	12	11.5	9.1	3.5	6.3
	14	130	86	45	92	15	12.3	10.8	2.9	6.9
	15	100	78	44	82	24	14.0	14.0	5.4	9.7
	16	700	82	43	90	19	11.3	8.9	2.5	5.7
	17	50	81	38	88	10	12.8	10.4	2.6	6.5
	20	[1] 650	73	45	76	25	6.0	5.0	4.2	4.6
	21	[1] 650	78	37	94	18	5.2	4.2	2.6	3.4
	22	[1] 700	80	41	87	25	5.7	4.6	4.9	4.8
	23	[1] 700	84	43	95	20	6.8	6.0	1.9	4.0
	24	[1] 700	89	43	90	19	6.0	5.2	1.9	3.6
	25	[1] 700	92	47	87	19	6.8	5.3	2.5	3.9
	28	300	80	37	82	14	6.3	5.2	1.7	3.5
Aug.	1	200	75	39	75	22	3.2	4.3	3.8	4.0
	2	200	78	38	88	23	2.2	2.2	2.4	2.3
	3	800	81	37	97	21	10.5	7.1	2.2	4.7
	4	700	77	40	94	22	13.2	10.9	2.1	6.5
	5	100	80	39	90	19	4.8	3.8	2.6	3.2
	6	[1] 25	85	39	92	14	4.2	2.7	1.9	2.3
	7	[1] 25	86	40	88	18	6.2	4.6	2.4	3.5
	8	[1] 25	84	45	90	25	8.8	6.4	2.2	4.3
	9	[1] 25	76	47	92	35	12.0	11.0	2.5	6.8
			BAD DAYS							
July	18	1,300	81	35	84	13	15.0	11.2	2.5	6.8
	19	1,600	72	48	65	22	10.0	9.7	8.2	8.9
	26	1,000	82	50	86	21	10.5	9.7	4.0	6.8
	27	1,900	73	51	60	23	10.2	11.0	6.2	8.6
	29	2,000	86	38	84	14	9.8	7.2	2.2	4.7
	30	1,400	88	42	94	15	10.8	7.4	2.2	4.8
	31	2,300	82	44	77	18	14.2	13.1	3.0	8.0

[1] Total for several days apportioned to each day of the period.

For all 28 days the conditions averaged as follows:

TABLE 2

Temperature: Average maximum, 81.6°; average minimum, 42.6°; average mean, 61.9°.

Relative humidity: Average maximum, 86.3%; average minimum, 19.7%; average mean, 53.0%.

Wind velocity: 6 p. m. to 6. a. m., average 3.1 miles per hour; 6 p. m. to 6 p. m., average 5.3 miles per hour; 6 a. m. to 6 p. m., average 7.5 miles per hour; Noon to 6 p. m., average 9.0 miles per hour.

The average temperatures were based on hourly temperatures from the thermograph records. The humidity averages are from the hygrograph records, checked against the sling psychrometer at least once each afternoon and very accurate for the lower humidities, but admittedly somewhat erratic for the higher. The wind velocities are the averages for the full hours specified, as recorded by the two-magnet register for the anemometer 150 feet above the ground, and 75 feet above the tops of surrounding trees.

A compilation of the records for the seven bad days shows that on these days the wind velocity was above the average for the duration of the fire, regardless of whether the afternoon wind, the daylight wind, the nighttime wind, or the average for 24 hours is considered. This is shown in tabular form as follows:

TABLE 3.—*Average wind velocity in excess of normal in miles per hour*

Average	6 p. m. to 6 a. m.	6 p. m. to 6 p. m.	6 a. m. to 6 p. m.	Noon to 6 p. m.
21 easy days	2.8	4.8	6.7	8.1
28 days	3.1	5.3	7.5	9.0
7 bad days	4.0	7.0	9.9	11.5

This arrangement of the data also brings out the fact that the nighttime wind was least dangerous and the noon to 6 p. m. velocity was nearly three times as great. It also indicates the need of forecasts of the daytime or better yet for the afternoon wind rather than the average for the 24-hour period. Few, if any, of the big runs made by the Quartz Creek fire occurred at night; nearly all were in the afternoon when the wind was at its worst. Regardless of temperature or humidity, it is obvious that the 7 days of greatest spread were marked by average wind velocities appreciably greater than on the other 21 days.

The records of relative humidity indicate a small but perhaps significant effect of this weather element in contributing to the big runs, as follows:

TABLE 4.—*Average relative humidity*

Average	Maximum	Minimum	Mean
	Per cent	Per cent	Per cent
21 easy days	88.9	20.1	54.5
28 days	86.3	19.7	53.0
7 bad days	78.6	18.4	48.5

The greatest difference here is found in the maximum humidity. This finding is in accordance with that of M. E. Dunlap, of the Forest Products Laboratory, through laboratory tests, indicating that a small change in the higher humidities causes a fairly large change in fuel moisture content, whereas a relatively large change

in the lower humidities produces a comparatively small change in fuel moisture. The fact that the minimum humidities did not vary greatly on the 7 bad days from the average for the 21 easy days further corroborates this conclusion. As previously stated, however, although the hygrograph used in studying the Quartz Creek fire was very accurate for the lower humidities, it was variably inaccurate at humidities of over 70%, hence perfect dependence can not be placed upon these variations of maximum humidity. About the only conclusions that can be drawn safely are that the average maximum humidity was 10% lower and the average minimum 2% lower on the bad days than on the days of least rapid spread, and that lower humidity probably contributed to the big runs of the fire.

The variations of temperature, the last weather factor to be considered, show no great agreement with the marked variations of this particular fire. The following averages were obtained from Table 1 in the same way as those previously given for relative humidity:

TABLE 5.—*Average temperature in °F.*

Average	Maximum	Minimum	Mean
	Per cent	*Per cent*	*Per cent*
21 easy days	81.7	42.1	61.9
28 days	81.6	42.6	61.9
7 bad days	80.6	44.0	62.3

In this case only the average minimum temperature was materially higher on the 7 bad days than on the 21 easy ones. The average maximum temperature is shown to have been 1.1° lower on the bad days, instead of higher, than on the easy ones. It is undoubtedly justifiable to conclude that neither maximum nor minimum temperature variations were of any great importance in controlling the spread of the Quartz Creek fire.

It should be noted that this conclusion applies to *variations* of temperature. From another viewpoint, that of the average temperature and humidity, both were undoubtedly of great importance in controlling the rate of spread and the ultimate size of the fire. As has been shown, the average maximum temperature for the duration of the fire was approximately 82° and the average minimum humidity about 20%. From Dunlap's study of the equilibrium relations between certain fuel moisture contents and temperature and humidity, it is known that if forest duff, twigs, slash, etc., are subjected to an atmosphere having a sustained temperature of 80° and a relative humidity of 20% the fuels will have a resultant moisture content of about 5%. For a sustained condition of 62° F. and 53% humidity, the means previously given, the equilibrium moisture content is about 10%. As 10% moisture in either wood or duff has been found by experiment to mean high inflammability and as 5% moisture content implies extremely dangerous dryness, it is obvious that the average temperatures and humidities during the Quartz Creek fire were sufficiently high and low, respectively, to favor very rapid spread of the fire. During the nights, when the average minimum temperature was 43° and the average maximum humidity was 86%, the fuels would have picked up moisture to a theoretical average amount of 20%, and only then should they have been appreciably less favorable to rapid spread of fire regardless of the wind.

Measurements made with the duff hygrometer show that the average duff moisture content was 13% at 8.30 a. m. and 7% at 4.45 p. m. on the fully exposed area during the days of the fire. The mean of these two is 10%, the same as deduced above on the basis of Dunlap's laboratory work. The differences between 13% and 20% and between 7% and 5% are attributed to the fact that sustained and constant temperatures and humidities were assumed in the theoretical deduction of the effects of these two weather elements on duff moisture. Actually, however, both temperature and humidity varied rapidly, and as duff moisture does not respond instantly to such changes, and as the mineral soil beneath the duff affects the fuel moisture, an appreciable lag is to be expected. The actual measurements of duff moisture therefore appear to agree with the theoretical deduction in showing that temperature and humidity combined to produce very dry fuels, which in turn favored rapid spread of fire throughout the 28 days under consideration.

CONCLUSIONS

The writer believes there is need of an accurate map of the controlled and uncontrolled fire front at the close of each day, so that the effects of suppression measures can be isolated, and so that area burned and perimeter of the fire can be computed for comparison with each of the important weather elements. In the present case the map shown was obtained primarily as an aid in studying the tactics of fire suppression actually used, and those that might better have been used.

It is apparent that with such a map the relative importance of certain weather factors can be roughly determined. In the present case it was found that mean temperatures of 62° F. or more, combined with mean relative humidities of 53% or less, occurring when the forest duff and branch wood have already dried out to less than 10% moisture content, implies a fuel condition conducive to very rapid spread of fire. Such conditions evidently warrant special preparedness in the future. It is further apparent that the big runs of a fire, under the above conditions, are influenced chiefly by wind direction and velocity; secondly, by small changes in relative humidity; and least of all by minor temperature changes. Forecasts of a 24-hour average wind velocity of 7 miles per hour should be recognized as implying much greater danger than forecasts of an average velocity of 4.8 or 5 miles per hour. As soon as possible the predictions of wind velocity should be refined to apply only to the daylight hours, and preferably to distinguish the afternoon hours. Indications for the occurrence of average maximum, minimum, and mean temperatures and humidities, such as those shown for the seven bad days of the Quartz Creek fire, likewise should be met with special preparedness.

The accuracy in later application of all of these findings is contingent upon similar conditions of fuels, topography, and fire suppression technique, all of which are admittedly important factors not considered in detail by the present study.

Another fact, of importance to all students of fire behavior, is the need of rather elaborate meteorological equipment which will provide graphic records of the weather elements. It should be obvious that irregular or infrequent measurements of temperature, humidity, and wind could not have been used in this study as easily as the continuous records. As large fires close to well equipped weather stations are not of common occurrence, it is altogether probable that special instruments must be developed which can be transported to the vicinity of large fires if much work similar to the present is to be conducted.

Clearly, an investigation of a single fire provides only a small fraction of all the evidence that must be accumulated before thoroughly dependable conclusions can be drawn. Other fires, under similar conditions of temperature, humidity, and wind, might exhibit entirely different behavior if the fuels, the topography, or the tactics of suppression differed materially. Several of these investigations must be made in each distinct timber type under different weather conditions before the major variations of fire behavior can be accurately related to the behavior of the weather.

INVESTIGATION OF RAINFALL PERIODICITIES BETWEEN 1 1/6 AND 2 1/2 YEARS BY USE OF SCHUSTER'S PERIODOGRAM

By DINSMORE ALTER

[University of Kansas, Lawrence, Kans., December, 1926]

SYNOPSIS

The present paper continues previous applications of Schuster's periodogram to the rainfall of the world, in this case for shorter periods than considered in them. The evidence continues favorable, and is even stronger than before, in favor both of the existence of what may be termed a "spectrum" of related periods and of their relation to the sun-spot period. It also begins to differentiate strongly between fairly constant periods and variable cycles, in favor of the former.

This paper and a short investigation of economic values of statistical examinations of rainfall periodicities to be published in the next issue of this REVIEW, complete a series of studies (*1*) of the rainfall of the world, begun about seven years ago. In these it was concluded definitely that periods or cycles do exist, but whether of constant length and amplitude remained uncertain.

The last few papers have been an application of Schuster's periodogram to these data and a study of the method itself. In each paper a stretch of shorter periods than the preceding ones has been considered.

Since Schuster's (*2*) original papers are available and also the preceding papers of this series which considered the method in detail, it is unnecessary to explain the method.

Given data $q_1 \ldots\ldots\ldots q_n$, assume any period P_j times the datum interval. Let φ_i be the phase angle for the datum q_i so that

$$\varphi_{i+1} - \varphi_i \equiv \frac{2\pi}{P}$$

$$\varphi_1 \equiv 0$$

$$A_j \equiv \sum_1^n q_i \cos\varphi_i$$

$$B_j \equiv \sum_1^n q_i \sin\varphi_i$$

$$I_j \equiv \frac{A^2{}_j + B^2{}_j}{n}$$

and is proportional to the square of the amplitude of the best sine curve of period P_j to fit the data.

$$\tan\Phi_j = \frac{B_j}{A_j};\quad I_{mean} = \frac{\sum_1^n \sigma^2{}_i}{2(n-1)}.$$

Where σ_i is the deviation of q_i from the mean q.

$$H_j \equiv \frac{I_j}{I_{mean}};\quad I'_j = I_j \frac{(x-y)^2}{4\sin^2 \tfrac{1}{2}(x-y)}.$$

where X is the phase of q_i and Y that of q_i+1 in radian measure. I' is the value of I which would have been secured had much shorter datum intervals been used. I not I' must be used in computing the probability of securing any given I by accident.

In this paper semiyearly rainfall means from the Pacific coast of the United States, from the Punjab and from the British Isles are used. These data, in the form of percentage departures from normal, are given as Table 1. The periods computed overlap those of the preceding paper. First, periodograms for periods between $1\frac{1}{16}$ and $2\frac{1}{2}$ years are computed from each half of the data of each of these sections. These chronologically independent periodograms are then compared. Finally a periodogram is computed from the total data of each section and conclusions drawn.

Before comparing these chronologically different periodograms a few points respecting the evidence given by periodograms may be considered.

(*a*) The fact that the peaks of chronologically different periodograms are of different intensity or of slightly different position is often considered as indicating variability of period. On page 480 of the October, 1924, MONTHLY WEATHER REVIEW are two very different appearing periodograms, made from different long stretches of data, composed by the addition of two sine curves of equal amplitude. When it is remembered that in these data there were only two periods and no accidental errors at all, the possibilities of variation, where the data may be composed of a whole spectrum of periods plus large accidental errors, are seen to be great enough almost to preclude evidence in favor of a variable cycle unless a very great number of such cycles have been completed.

(*b*) The comparison of periodograms by Pearson's correlation coefficient, while useful, minimizes the relationship between them for the following reasons:

1. Suppose that in the periodograms one real peak is shown equally in both. This one peak will give a positive correlation but all the rest will give a zero correlation, since the theory of the periodogram shows that it varies under the accidental error law, except in the vicinity of real periods. We would, therefore, in this case, expect from the periodograms a small positive coefficient, comparable with the probable error, and telling us, therefore, little or nothing. *A large positive correlation becomes strong evidence, consequently, in favor of a whole spectrum of real periods even where the separate peaks may be too low in height to carry much weight individually.*

2. If there are variable cycles, or if the interference of periods, or the accidental errors, have produced slight shifts in the positions of peaks, the two periodograms will give a negative coefficient, sometimes very large. This is beautifully illustrated in the periodograms of the Pacific coast. At about 2.30 years a high peak starts in each. At about 2.33 years the one from the early data reaches its maximum H=4.8, here exactly coinciding with the later periodogram. This later one continues to rise to H=10.5, while the earlier one falls rapidly. One half indicates a period at P=2.33 years, the other at P=2.44,

each within the accidental range of their mean, yet they give such large negative terms to what is otherwise a rather large positive correlation as to reduce it practically to zero.

3. In computing the correlation coefficient the use of the computed I_m magnifies the apparent relationship, and the use of the measured just as obviously decreases it. In results given in this paper the measured I_m has always been used.

In forming the six month means for use in this paper, the same monthly means of the Pacific coast and of the

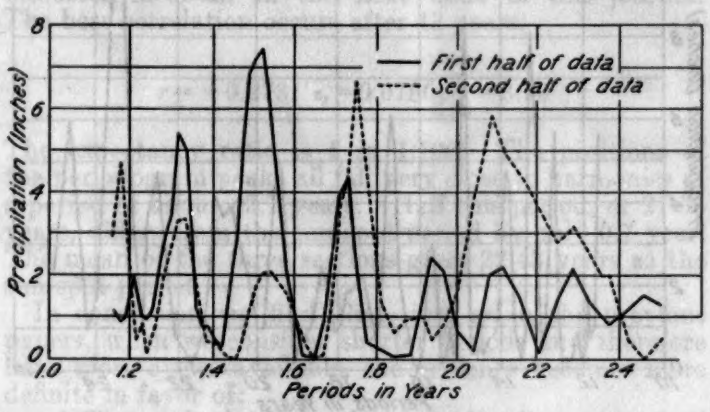

FIG. 1.—Rainfall periodogram of the Punjab

Punjab were used as in the last paper. For the British Isles additional data were received through the United States Weather Bureau and the monthly percentages of normal of Armagh, Chilgrove, Edinburgh, Greenwich, and Stonyhurst were averaged.[1]

We shall discuss the data in the order of definiteness of the results, taking the Punjab, which is least definite, first. This is to be expected, for while the same number of years are used in the earlier periodogram as for other sections, the latter, because of the shorter stretch, has about two dozen less from which to compute the periodogram. The three periodograms from the entire stretch of data will be included in one discussion after that of all those from the halves of the data have been completed. We find that now when we have shorter periods, and, therefore, a greater number of cycles, the values of H are greater than in the last paper, the highest being 7.48 and 5.40 in the first half of the data and 6.44 and 5.77 in the second half. In the last paper the highest peaks were $H=4.26$ and 3.41. There the values were entirely inconclusive; here they are quite definite in their indication of reality. The accidental expectancy ratio of $H=7.48$ is one in 2,100. If our data followed the accidental laws the H's should be of about the same height regardless of the number of cycles completed. If there be a spectrum of real periodicities between long and short periods we should find just as we have, that H increases with the number of cycles.

The periodograms are plotted as Figure 1, which brings out their similarities and divergencies. We see that except at the extreme ends of the periodograms there is an almost perfect agreement in the positions of the peaks of these chronologically independent periodograms. Remembering the limitations to the application of the correlation coefficient we shall nevertheless compute it and find $r=+0.167$; $\epsilon_r=0.0868$; $\frac{r}{\epsilon_r}=1.925$. Such a correlation, although somewhat favorable, is not at all definite, since one pair out of every 47 pairs of curves should give a relationship of this size by mere accident. However, a glance at the periodograms shows that this low coefficient has come, not from the usual error distribution of dissimilarities but from the ends of the curves, especially the end of longer periods. Here the later curve shows a high peak with a slight side protuberance, while the early curve shows, *in exactly the same place*, two low peaks. These are twice as high as the computed mean and would, therefore, give a positive correlation if we had used it instead of the measured mean. However, on account of the high peaks appearing in the periodograms, they are lower than that measured and for this reason give in combination with the high peak a very large negative correlation. If we omit these ends, using all the points 16–54, we find that these 39 central points give $r=+0.339$ which is 3.55 times its probable error. The accidental expectancy ratio of such a correlation is one in 1,200, indicating a correlation far higher than we would expect from mere accident. The indications are, therefore, that several periods or cycles did persist throughout both halves of the data with a constancy greater than we could expect through accident.

When we turn to the Pacific coast periodograms we find a very similar situation, although here the lower peak has capsized after starting up with the higher one. Here, on account of the fact that the high peak is truly remarkable, being 10.50 times the computed mean, the negative factors introduced lower the correlation, although it is still slightly positive, to less than its probable error. Once more we must notice that the use of the computed mean height would have given a positive correlation between these peaks. Using the same 39 central points which we used for The Punjab, we obtain $r=+0.435$, $\epsilon_r=0.0876$ and $\frac{r}{\epsilon_r}=4.96$. The accidental expectancy

FIG. 2.—Rainfall periodogram of the U. S. Pacific coast

ratio of such a correlation is one in 20,300, a quite definite proof of relationship. Entirely apart from the mathematical proof given by these correlations, a mere visual examination shows quite well the persistancy of the spectrum of periods.

In the case of the periodograms of the British Isles a glance is sufficient to show that the relationship can not be accidental. Throughout the length of the curves there is scarcely a disagreement. Out of ten peaks, nine show almost perfect agreement. None are high but

[1] These data are British Isles A, of Table 1. Since reading this paper at Philadelphia, still more data have been received. These lengthen the records and give Rothesay as an additional station. The new means, not used in this paper, are given as British Isles B. They are being used in a numerical example to demonstrate the value of a new form of periodogram.

we can not doubt at all their reality and approximate constancy. We find $r=+0.432$; $\epsilon_r=0.0726$; $\frac{r}{\epsilon_r}=5.96$. This ratio tells us in exact numbers what inspection has already told us, i. e., that the peaks are real. The expectancy ratio is one in 150,200.

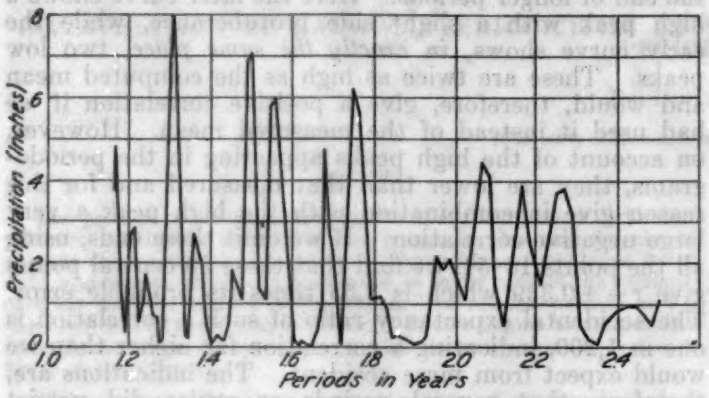

FIG. 3.—Rainfall periodogram of the British Isles

Before we turn to the periodograms computed from the entire data stretches, we must consider one or two points of theory.

(*a*) If the periods are accidents, the peaks found in the periodograms from halves of the data should have H as high as from the whole stretch. If they are real and approximately constant, the H's should increase in height and if they are more than slightly variable the H's should decrease very much.

(*b*) The "spectroscope," for the periodogram may well be called such, has four times the resolving power when applied to these double data stretches. Where, previously, peaks merged or displaced each other, they may now be separated. Magnitudes and positions will be determined more accurately. Low peaks, which were comparable with the accidental errors, will begin to appear in their true form.

From the first half of the data of the Punjab the highest peaks are $H=7.48$, 5.40, and 4.42. From the latter half they are $H=6.64$, 5.77, and 4.73. From the total stretch they are $H=7.98$, 7.08, 6.23, and 6.01, a very substantial and consistent gain. The expectancy ratio of the highest of these is one in 2,900; that of the lowest of the four is one in 410. The first half of the Pacific Coast data gives $H=5.90$, 5.84, and 5.20, the latter half gives $H=10.50$, 5.03, and 3.79. The H's from all of the data

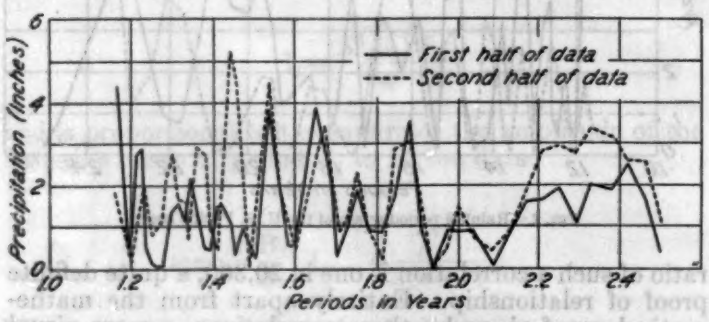

FIG. 4.—Rainfall periodogram of the Punjab (entire data series)

are 10.60, 8.55, 8.18, and 6.13. It is true that the gain in the case of the highest peak is almost negligible, but the consistency of the other gains makes our evidence just as definite as it was before. The expectancy ratios for these four highest peaks vary from one in 460 to one in 40,000.

Naturally, from what the halves disclosed, the British Isles data should show by far the best evidence. The first half of the data gives $H=4.43$, 3.90, and 3.86; the latter half $H=5.33$, 4.53, and 3.40. The total stretch given $H=8.35$, 6.18, 5.54, and 5.19, a truly remarkable gain in height. The expectancy ratios vary from one in 175 to one in 4,200.

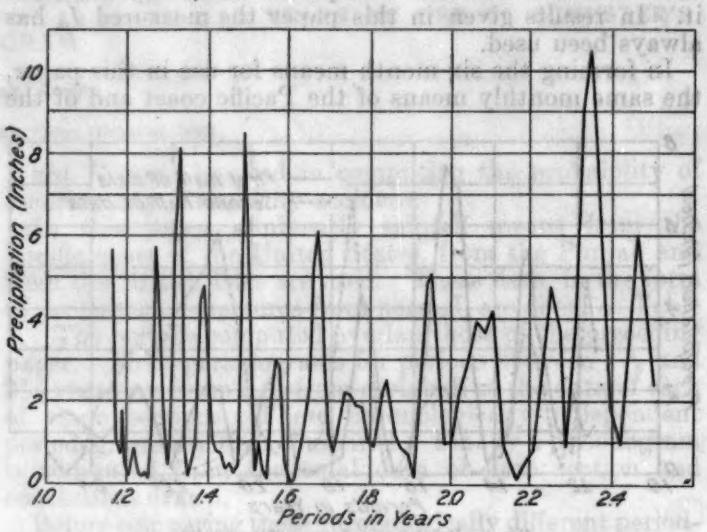

FIG. 5.—Rainfall periodogram of the Pacific coast (entire data series)

We have in previous papers considered very carefully the relationship of rainfall periods to the sun-spot period and have seen a very marked bias, enough to make it possible to compute the sun-spot period with accuracy from the rainfall data. In this section of the work the distance between adjacent harmonics is so small that slight displacements of the peaks by the accidental errors will cause the relationship to disappear. There is, however, a method by which it is possible to weigh the evidence submitted by the data as a whole. If there be a bias, the correlation coefficient between stretches of data separated by the sun-spot period or a multiple of it should be larger than would be expected by accident. It must be remembered, however, that we are able only to compare after an exact number of datum intervals and that, therefore, the correlation will be lower in general than

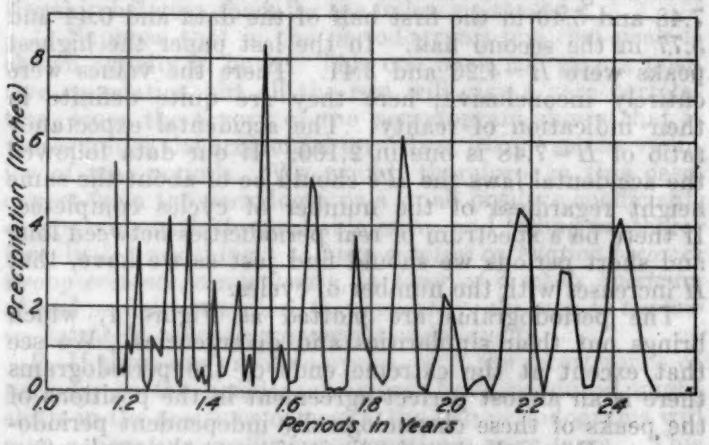

FIG. 6.—Rainfall periodogram of the British Isles (entire data series)

if we could match stretches more accurately. The Punjab shows the simplest relationship. Inspection shows a similarity after 47 phases or 23½ years. The correlation computed is $r=+0.202$; $\epsilon_r=0.0737$; $\frac{r}{\epsilon_r}=2.75$, which corresponds to an expectancy ratio of one to 243.

In the case of the other two sections we find that the correlation occurs after double the sun-spot period. For the Pacific coast the correlation is best after 89 phases, or 44½ years. It is

$$r = +0.194;\ \epsilon_r = 0.0860;\ \frac{r}{\epsilon_r} = 2.25$$

The expectancy ratio of such is 1 in 90. The period is exactly twice the sun-spot period.

The British Isles are much more exact and will be discussed in detail in the next issue of this journal. The best correlation occurs after 43 years.

$$r = +0.273;\ \epsilon_r = 0.0780;\ \frac{r}{\epsilon_r} = 3.50$$

The expectancy ratio is 1 in 1,100. The positions of the periodogram peaks all fall very close to harmonics of a period of about 43.1 years. Half this period, or 21.55 years, differs from the sun-spot period by only 0.7 year. The mean of the three sections gives 22.43 years as the sun-spot period.

In conclusion we find that, just as in the previous papers, when we consider shorter periods and therefore have more cycles available, the evidence becomes more definite in favor of:

(*a*) The real physical existence of a "spectrum" of rainfall periods.

(*b*) The relationship of rainfall periods to the sun-spot period.

(*c*) The approximate constancy of rainfall periods, in length at least.

Evidence against constancy of their magnitudes is lacking.

Beyond this, all is more or less speculation; and while it seems that the time has come for some sufficiently guarded speculation, the consideration of economic value clearly belongs in a separate paper.

The research committee of the Graduate School of the University of Kansas have assisted in this work by a grant through which computers were engaged to do more than half the routine computing. The Chief of the United States Weather Bureau and other officials there have very kindly made data available, even to the extent of making manuscript copies where necessary. As in all these papers, Professor Kester has encouraged and advised, contributing greatly to whatever success the work may find.

TABLE 1.—*Percentage departures from normal precipitation, by half years,*[1] *for selected regions, 1834–1924*

Year	Pacific coast	British isles A	The Punjab	British isles B	Year	Pacific coast	British isles A	The Punjab	British isles B
1834	------	------	------	−15	1836	------	------	------	+21
	------	------	------	−11		------	------	------	+23
1835	------	------	------	+4	1837	------	------	------	−12
	------	------	------	−1		------	------	------	−9

[1] The upper value of each section, given opposite each year, is the percentage of normal of that section for the first half of the year; the lower value for the second half of the year.

TABLE 1.—*Percentage departures from normal precipitation, by half years, for selected regions, 1834–1924*—Continued

Year	Pacific coast	British isles A	The Punjab	British isles B	Year	Pacific coast	British isles A	The Punjab	British isles B
1838	------	------	------	+6	1882	−11	+14	−27	+14
	------	------	------	−2		−19	+16	+10	+20
1839	------	------	------	−7	1883	−5	−6	−16	−3
	------	------	------	+28		−37	−3	−20	−1
1840	------	------	------	−12	1884	+87	−6	−21	−4
	------	------	------	−7		+45	−16	+12	−11
1841	------	------	------	+13	1885	−54	−3	+40	−3
	------	------	------	+32		+54	−21	−15	−19
1842	------	------	------	−21	1886	+20	+10	+53	+6
	------	------	------	−14		−47	+4	−3	+3
1843	------	------	------	+11	1887	−2	−38	−62	−37
	------	------	------	−11		−27	−16	+22	−16
1844	------	------	------	−9	1888	−11	−9	−36	−9
	------	------	------	−21		+20	+6	+5	+3
1845	------	------	------	−9	1889	−20	−11	+16	−12
	------	------	------	+3		+134	−10	−11	−11
1846	------	------	------	+9	1890	+17	−5	+32	−2
	------	------	------	+9		−40	−4	+26	+1
1847	------	------	------	−24	1891	−11	−30	+1	−30
	------	------	------	−14		−23	+21	−21	+22
1848	------	------	------	+42	1892	−16	−16	−59	−13
	------	------	------	+9		+34	−3	+47	+1
1849	------	------	------	+3	1893	+2	−35	+92	−32
	------	------	------	−9		−7	−2	+23	−2
1850	------	−9	------	+1	1894	−5	+22	+92	+22
	------	−18	------	−16		+26	−1	+34	−4
1851	------	+12	------	+12	1895	+13	−32	+43	−33
	------	−35	------	−31		−37	+12	−33	+11
1852	−30	+6	------	+7	1896	+14	−20	−30	−18
	+138	+55	------	+41		+20	+13	−39	+5
1853	+3	+12	------	+5	1897	−4	+22	−33	+17
	−22	+7	------	+4		−33	−13	−11	−13
1854	+8	−22	------	−13	1898	−50	−7	−6	−7
	−22	−32	------	−25		−43	−12	−15	−12
1855	+23	−30	------	−29	1899	−5	+14	−38	+15
	−28	−4	------	−9		+28	−10	−70	−7
1856	−4	+16	------	+13	1900	−24	+9	−36	+8
	−25	−10	------	−12		−5	+9	+38	+12
1857	−8	−15	------	−9	1901	+8	−4	+7	−9
	+20	−6	------	−10		−21	−9	−13	−9
1858	+15	−20	------	−11	1902	+4	−7	−24	−9
	+24	−18	------	−17		+8	−21	−10	−17
1859	−18	−11	------	−1	1903	−5	+33	−39	+30
	+26	+9	------	+8		−36	+27	+25	+28
1860	−1	+34	------	+31	1904	+9	+12	+22	+13
	+16	+25	------	+14		+14	−20	−14	−18
1861	−5	−17	------	−15	1905	+19	−3	−4	−3
	+68	+4	------	+11		−43	−18	−11	−17
1862	+77	+29	------	+30	1906	+48	+15	+35	+15
	−54	−5	------	+1		+30	−4	+25	−2
1863	−19	−1	+21	+3	1907	+32	+14	+51	+14
	−39	−18	+50	−14		−13	−4	−29	−3
1864	−44	−14	−5	−13	1908	−23	+3	−20	+4
	+44	−18	−8	−18		−38	−9	+86	−6
1865	−27	−2	+36	−7	1909	+44	+3	+15	+4
	−4	+5	+17	+1		+46	+5	+40	+2
1866	+32	+20	−8	+19	1910	−29	+18	−13	+17
	+66	+11	−3	+13		−37	−4	+17	−4
1867	+31	+17	−22	+16	1911	+36	−10	+79	−6
	+108	−12	+1	−12		−51	−5	−43	−3
1868	+23	−2	+11	+5	1912	−1	+10	−16	+13
	−20	−2	−44	−2		−40	+7	−1	+7
1869	+9	+12	+13	+7	1913	−30	+14	+36	+16
	−24	−11	−2	−8		+15	−21	−4	−22
1870	−24	−32	−23	−28	1914	+20	+1	+32	+2
	−46	−9	−25	−12		−19	+3	+65	+2
1871	−25	+4	+23	+6	1915	+26	+3	+10	+5
	+63	−1	−39	−6		−7	+16	−45	+10
1872	−8	+31	+4	+33	1916	+38	+31	−36	+29
	−7	+28	+21	+31		0	+11	+45	+10
1873	−30	−14	−54	−18	1917	−22	−9	+18	−8
	+35	0	+21	+5		−71	+2	+127	+3
1874	+7	−25	+9	−25	1918	−3	−12	−10	−9
	−12	+2	−18	+5		+8	+26	−52	+27
1875	−9	−17	−53	−18	1919	0	+6	−14	+5
	+50	+15	+75	+11		−41	−7	+17	−5
1876	+21	0	−21	0	1920	−31	+16	−12	+25
	−49	+16	+11	+15		+12	−10	−40	−5
1877	−43	+33	+72	+34	1921	−4	−24	−75	−16
	−24	+15	−19	+20		+37	−13	+23	−6
1878	+73	+11	+18	+11	1922	−12	−3	−36	+5
	−50	−10	+13	−12		+31	−11	+5	−11
1879	+29	+24	−2	+23	1923	−33	+1	+7	+5
	+22	−4	−22	−2		−49	+15	+23	+22
1880	+23	−9	−23	−10	1924	−49	+2	−14	+2
	+49	+25	−22	+17		0	+21	+30	+22
1881	+6	−3	+2	−1					
	−36	+10	+2	+10					

TABLE 2.—*Rainfall periodograms for 2½ to 1⅙ years*

		Pacific coast								British Isles								The Punjab							
Mean L....		Old				New				Old				New				Old				New			
		811.0				527.3				163.3				110.5				547.0				779.1			
P	F	I	H	H′	A	I	H	H′	A	I	H	H′	A	I	H	H′	A	I	H	H′	A	I	H	H′	A
2½	1.142	251	0.31	0.35	0.56	3,091	5.86	6.70	2.59	68	0.42	0.48	0.69	143	1.29	1.47	1.21	737	1.35	1.54	1.24	384	0.49	0.56	0.75
2⅓	1.147	731	0.90	1.03	1.01	5,548	10.50	12.04	3.47	279	1.71	1.96	1.39	279	2.52	2.89	1.70	870	1.59	1.82	1.35	18	0.02	0.02	0.14
2¼	1.153	1,625	2.00	2.31	1.52	5,504	10.44	12.05	3.47	406	2.49	2.87	1.70	285	2.58	2.98	1.73	666	1.22	1.41	1.19	417	0.54	0.62	0.79
2⅕	1.159	2,949	3.64	4.21	2.05	5,223	9.90	11.47	3.38	312	1.91	2.21	1.49	353	3.20	3.70	1.92	416	0.76	0.88	0.94	1,558	2.00	2.32	1.52
2⅙	1.165	3,939	4.86	5.66	2.38	2,568	4.87	5.67	2.38	333	2.04	2.38	1.54	375	3.39	3.95	1.99	769	1.41	1.64	1.28	1,547	1.99	2.32	1.52
2⅐	1.172	3,416	4.21	4.94	2.22	679	1.29	1.51	1.23	179	1.10	1.29	1.14	306	2.77	3.25	1.80	1,200	2.19	2.57	1.60	2,470	3.17	3.72	1.93
2¼	1.179	2,272	2.80	3.30	1.82	995	1.89	2.23	1.49	320	1.96	2.31	1.52	324	2.93	3.45	1.86	775	1.42	1.67	1.29	2,144	2.75	3.24	1.80
2⅛	1.187	759	0.94	1.11	1.05	1,999	3.79	4.50	2.12	267	1.64	1.95	1.39	300	2.72	3.23	1.80	79	0.14	0.17	0.41	2,759	3.54	4.20	2.05
2⅑	1.195	609	0.75	0.90	0.95	1,815	3.44	4.11	2.03	255	1.56	1.86	1.37	192	1.74	2.08	1.44	779	1.52	1.82	1.35	3,380	4.34	5.19	2.28
2⅒	1.204	2,670	3.29	3.97	1.99	626	1.19	1.43	1.19	136	0.83	1.00	1.00	98	0.89	1.07	1.03	1,214	2.22	2.68	1.64	3,817	4.90	5.90	2.43
2⅑	1.213	4,220	5.20	6.32	2.51	47	0.09	0.11	0.33	20	0.12	0.15	0.39	52	0.47	0.57	0.76	1,092	2.00	2.43	1.56	4,496	5.77	7.00	2.65
2⅛	1.223	2,929	3.61	4.42	2.10	110	0.21	0.26	0.51	133	0.81	0.99	0.99	77	0.70	0.86	0.93	131	0.24	0.29	0.54	3,050	3.92	4.80	2.19
2	1.233	2,721	3.36	4.15	2.04	607	1.15	1.42	1.19	130	0.80	0.99	0.99	168	1.52	1.88	1.37	345	0.63	0.78	0.88	1,320	1.70	2.10	1.45
1⅞	1.242	3,569	4.40	5.47	2.33	986	1.87	2.33	1.52	138	0.85	1.06	1.03	60	0.54	0.67	0.82	1,144	2.09	2.60	1.61	633	0.81	1.01	1.00
1⅞	1.252	2,534	3.12	3.91	1.98	941	1.79	2.24	1.50	14	0.09	0.11	0.33	1	0.01	0.01	0.10	1,327	2.43	3.04	1.75	392	0.50	0.63	0.80
1⅞	1.261	931	1.15	1.45	1.20	219	0.42	0.53	0.73	150	0.92	1.16	1.08	156	1.41	1.78	1.34	787	1.44	1.82	1.35	753	0.97	1.22	1.11
1⅞	1.271	1,301	1.61	2.05	1.43	109	0.21	0.27	0.52	585	3.58	4.56	2.14	341	3.09	3.93	1.99	71	0.13	0.17	0.41	702	0.90	0.11	0.33
1⅞	1.280	1,597	1.97	2.52	1.59	894	1.70	2.18	1.48	269	1.65	2.11	1.45	317	2.87	3.68	1.92	51	0.09	0.12	0.35	464	0.60	0.08	0.28
1⅞	1.291	118	0.15	0.19	0.44	815	1.54	1.99	1.41	140	0.86	1.11	1.05	28	0.25	0.32	0.57	140	0.26	0.34	0.58	1,058	1.36	1.76	1.33
1⅞	1.304	861	1.06	1.38	1.17	290	0.55	0.72	0.85	147	0.90	1.17	1.08	100	0.91	1.19	1.09	229	0.42	0.50	0.71	2,809	3.61	4.71	2.17
1⅞	1.318	2,812	3.47	4.58	2.14	8	0.02	0.03	0.17	314	1.92	2.53	1.59	261	2.36	3.11	1.77	1,439	2.63	3.47	1.86	5,165	6.64	8.75	2.96
1⅞	1.327	1,551	1.91	2.54	1.59	107	0.20	0.27	0.52	160	0.98	1.30	1.14	146	1.32	1.75	1.32	2,419	4.42	5.87	2.42	3,385	4.35	5.78	2.40
1⅞	1.336	152	0.19	0.25	0.50	613	1.16	1.55	1.24	62	0.38	0.51	0.71	95	0.86	1.15	1.07	2,116	3.87	5.17	2.28	2,851	3.66	4.89	2.21
1⅞	1.346	1,649	2.03	2.73	1.65	1,201	2.28	3.07	1.75	364	2.23	3.00	1.73	242	2.19	2.95	1.72	1,380	2.52	3.39	1.84	975	1.25	1.68	1.30
1⅞	1.356	2,751	3.39	4.60	2.14	1,966	3.73	5.06	2.25	523	3.20	4.34	2.08	375	3.40	4.61	2.15	489	0.89	1.21	1.10	219	0.11	0.15	0.39
1⅞	1.367	2,416	2.98	4.07	2.02	2,648	5.03	6.88	2.62	637	3.90	5.33	2.31	314	2.84	3.88	1.97	18	0.03	0.04	0.20	10	0.01	0.01	0.10
1⅞	1.379	1,632	1.99	2.74	1.65	2,416	4.58	6.32	2.51	287	1.76	2.43	1.56	145	1.31	1.80	1.34	38	0.07	0.10	0.32	301	0.39	0.54	0.74
1⅞	1.391	2,148	2.65	3.69	1.92	1,907	3.62	5.04	2.24	85	0.52	0.72	0.85	49	0.44	0.61	0.78	433	0.79	1.10	1.05	846	1.09	1.52	1.23
1⅞	1.404	2,702	3.33	4.68	2.16	1,353	2.57	3.61	1.90	86	0.53	0.74	0.86	143	1.29	1.81	1.35	1,195	2.19	3.08	1.76	1,227	1.58	2.22	1.49
1⅞	1.417	1,484	1.83	2.59	1.61	250	0.47	0.67	0.82	340	2.08	2.95	1.99	217	1.97	2.79	1.67	2,519	4.60	6.52	2.56	1,429	1.84	2.61	1.62
1⅞	1.431	141	0.17	0.24	0.49	88	0.17	0.24	0.49	630	3.86	5.53	2.36	501	4.53	6.49	2.55	3,513	6.43	9.20	3.04	1,619	2.08	2.98	1.73
1⅞	1.446	3,010	3.71	5.36	2.31	1,444	2.74	3.96	1.99	330	2.02	2.92	1.71	301	2.72	3.93	1.98	4,085	7.48	10.81	3.29	1,583	2.04	2.95	1.72
1⅞	1.462	3,121	3.85	5.64	2.37	1,600	3.04	4.45	2.11	45	0.28	0.41	0.64	98	0.89	1.30	1.14	3,920	7.17	10.50	3.24	1,301	1.67	2.45	1.57
1⅞	1.475	3,947	4.87	7.19	2.68	860	1.63	2.40	1.55	98	0.60	0.89	0.94	4	0.04	0.06	0.24	3,709	6.79	10.01	3.17	865	1.11	1.64	1.28
1⅞	1.488	1,084	1.34	1.99	1.41	338	0.64	0.95	0.97	159	0.97	1.44	1.20	260	2.35	3.50	1.87	2,961	5.42	8.07	2.84	214	0.27	0.40	0.63
1⅞	1.501	86	0.11	0.17	0.41	282	0.53	0.80	0.89	63	0.39	0.59	0.77	511	4.62	6.94	2.64	1,666	3.05	4.59	2.14	33	0.04	0.06	0.25
1⅞	1.515	231	0.28	0.42	0.65	1,031	1.96	2.97	1.72	180	1.10	1.67	1.29	589	5.33	8.08	2.84	768	1.40	2.12	1.46	34	0.04	0.06	0.25
1⅞	1.529	318	0.39	0.60	0.77	1,742	3.31	5.06	2.25	261	1.60	2.45	1.57	193	1.75	2.68	1.64	161	0.29	0.44	0.66	128	0.16	0.24	0.49
1⅞	1.544	913	1.13	1.75	1.32	1,528	2.90	4.48	2.11	240	1.47	2.27	1.51	50	0.45	0.70	0.84	243	0.44	0.68	0.83	300	0.39	0.60	0.77
1⅞	1.560	2,036	2.51	3.92	2.06	1,360	2.58	4.03	2.01	72	0.44	0.69	0.83	106	0.96	1.50	1.23	392	0.72	1.13	1.06	381	0.49	0.76	0.87
1⅞	1.577	2,662	3.28	5.17	2.27	269	0.51	0.80	0.89	87	0.53	0.84	0.92	302	2.73	4.31	2.08	392	0.72	1.13	1.06	585	0.75	1.18	1.09
1⅞	1.594	943	1.16	1.85	1.36	30	0.06	0.09	0.30	244	1.49	2.38	1.54	322	2.91	4.65	2.16	694	1.27	2.03	1.43	1,288	1.65	2.63	1.62
1⅞	1.612	2,534	3.12	5.03	2.24	825	1.57	2.53	1.59	370	2.26	3.65	1.91	82	0.74	1.19	1.09	1,865	3.41	5.50	2.35	1,996	2.56	4.13	2.03
1⅞	1.631	4,742	5.84	9.54	3.08	1,363	2.59	4.23	2.06	188	1.15	1.88	1.37	160	1.45	2.37	1.54	2,727	4.99	8.15	2.86	2,636	3.38	5.52	2.35
1⅞	1.652	2,761	3.41	5.65	2.38	1,030	1.84	3.04	1.74	240	1.47	2.43	1.56	176	1.59	2.63	1.62	2,948	5.40	8.93	2.99	2,612	3.35	5.54	2.36
1⅞	1.674	587	0.72	1.21	1.10	26	0.05	0.08	0.28	222	1.36	2.28	1.51	290	2.63	4.40	2.10	1,906	3.49	5.85	2.42	1,913	2.45	4.10	2.02
1⅞	1.697	2,514	3.10	5.27	2.29	557	1.06	1.80	1.34	8	0.05	0.08	0.28	237	2.15	3.65	1.91	1,463	2.68	4.55	2.13	1,420	1.82	3.09	1 76
1⅞	1.721	2,975	3.67	6.32	2.51	1,446	2.74	4.72	2.17	7	0.04	0.07	0.26	132	1.20	2.07	1.44	946	1.73	2.99	1.73	569	0.73	1.26	1.12
1⅞	1.746	710	0.88	1.54	1.24	1,153	2.19	3.82	1.96	28	0.17	0.30	0.55	82	0.74	1.29	1.14	598	1.09	1.90	1.38	373	0.48	0.84	0.92
1⅞	1.763	384	0.47	0.83	0.91	800	1.52	2.68	1.64	90	0.55	0.97	0.98	120	1.09	1.92	1.39	516	0.94	1.66	1.29	133	0.17	0.30	0.55
1⅞	1.781	1,345	1.66	2.96	1.72	554	1.05	1.87	1.37	333	2.04	3.64	1.91	222	2.01	3.58	1.89	569	1.04	1.85	1.36	61	0.78	1.39	1.18
1⅞	1.800	1,365	1.68	3.03	1.74	344	0.65	1.17	1.08	461	2.82	5.08	2.26	175	1.58	2.84	1.69	788	1.44	2.59	1.61	324	0.42	0.76	0.87
1⅞	1.820	498	0.61	1.11	1.05	4	0.08	0.15	0.39	430	2.63	4.79	2.19	98	0.89	1.62	1.27	1,064	1.95	3.55	1.89	675	0.87	1.58	1.26
1⅞	1.836	271	0.33	0.61	0.78	129	0.24	0.44	0.66	134	0.82	1.50	1.23	13	0.12	0.22	0.47	764	1.40	2.57	1.60	1,307	1.68	3.08	1.76
1⅞	1.861	2,143	2.64	4.92	2.21	615	1.17	2.18	1.48	76	0.47	0.88	0.94	54	0.49	0.91	0.94	527	0.96	1.79	1.34	2,907	3.85	7.17	2.68
1⅞	1.883	4,296	5.29	9.97	3.15	904	1.71	3.22	1.80	432	2.65	5.00	2.24	131	1.19	2.25	1.50	476	0.87	1.64	1.28	3,678	4.73	8.93	2 99
1⅞	1.907	4,780	5.90	11.25	3.35	318	0.60	1.14	1.07	723	4.43	8.45	2.91	199	1.80	3.43	1.85	643	1.18	2.25	1.50	2,275	2.92	5.57	2.36

TABLE 3.—*Rainfall periodograms (entire data series) for 2¼ to 1⅛ years*

		Pacific coast				British Isles				The Punjab			
Mean I...		664.5				136.0				636.9			
P	F	I	H	H'	A	I	H	H'	A	I	H	H'	A
2½	1.142	1,579	2.38	2.72	1.65	9	0.07	0.08	0.28	666	1.05	1.20	1.10
2⅖	1.147	2,980	4.48	5.12	2.28	76	0.56	0.64	0.80	326	0.51	0.58	0.76
2⅓	1.147	3,981	5.99	6.86	2.62	265	1.95	2.24	1.50	488	0.77	0.88	0.94
2¼	1.150	2,508	3.78	4.35	2.09	455	3.34	3.84	1.96	618	0.97	1.12	1.06
2¼	1.153	623	0.94	1.08	1.04	572	4.21	4.86	2.20	619	0.97	1.12	1.06
2⅛	1.156	1,225	1.84	2.13	1.46	481	3.53	4.08	2.02	514	0.81	0.94	0.97
2⅜	1.159	4,973	7.49	8.68	2.95	236	1.74	2.02	1.42	378	0.59	0.68	0.82
2⅛	1.162	7,047	10.60	12.32	3.51	36	0.26	0.30	0.55	39	0.06	0.07	0.26
2⅝	1.165	5,940	8.94	10.41	3.23	28	0.21	0.24	0.49	135	0.21	0.24	0.49
2¼	1.168	2,435	3.66	4.27	2.07	172	1.27	1.48	1.22	364	0.57	0.67	0.82
2⅓	1.172	606	0.91	1.07	1.03	388	2.85	3.34	1.83	2,002	3.14	3.68	1.92
2⅛	1.175	2,463	3.71	4.36	2.09	397	2.92	3.43	1.85	2,364	3.71	4.36	2.09
2⅔	1.179	3,161	4.76	5.61	2.37	144	1.06	1.25	1.12	2,347	3.69	4.35	2.09
2⅛	1.183	1,417	2.13	2.52	1.59	1	0.01	0.01	0.10	1,427	2.24	2.65	1.63
2¼	1.187	532	0.80	0.95	0.97	145	1.07	1.27	1.13	889	1.39	1.65	1.28
2¼	1.191	336	0.51	0.61	0.78	566	4.16	4.95	2.22	1,613	2.53	3.01	1.73
2⅜	1.195	106	0.16	0.19	0.44	602	4.42	5.23	2.29	2,490	3.91	4.67	2.16
2⅛	1.199	582	0.88	1.06	1.03	438	3.22	3.86	1.96	1,508	2.37	2.84	1.69
2⅝	1.204	1,921	2.89	3.48	1.87	83	0.61	0.74	0.86	511	0.49	0.59	0.77
2¼	1.208	2,841	4.28	5.17	2.27	2	0.01	0.01	0.10	923	1.45	1.75	1.32
2⅓	1.213	2,370	3.57	4.33	2.08	65	0.48	0.58	0.76	2,617	4.13	5.01	2.24
2⅛	1.218	2,626	3.95	4.81	2.19	45	0.33	0.40	0.63	2,846	4.47	5.44	2.33
2⅔	1.223	1,877	2.82	3.45	1.86	1	0.01	0.01	0.10	1,697	2.66	3.25	1.80
2⅛	1.228	1,488	2.24	2.63	1.62	132	0.97	1.19	1.09	709	1.11	1.36	1.17
2	1.233	660	0.99	1.22	1.10	264	1.94	2.39	1.55	1,059	1.66	2.05	1.43
1⅘	1.238	630	0.95	1.18	1.09	325	2.39	2.96	1.72	1,385	2.17	2.69	1.64
1⅗	1.242	1,767	2.66	3.30	1.82	136	1.00	1.24	1.11	1,180	1.85	2.30	1.52
1⅖	1.247	3,381	5.09	6.34	2.52	48	0.35	0.44	0.66	1,419	2.23	2.78	1.67
1⅕	1.252	3,220	4.85	6.07	2.46	1	0.01	0.01	0.10	983	1.54	1.93	1.39
1⅘	1.257	1,540	2.32	2.92	1.71	16	0.12	0.15	0.39	157	0.25	0.31	0.56
1⅗	1.261	106	0.16	0.20	0.45	192	1.41	1.78	1.33	105	0.16	0.20	0.45
1⅖	1.266	431	0.65	0.82	0.91	667	4.90	6.20	2.49	30	0.05	0.06	0.24
1⅓	1.271	566	0.85	1.08	1.04	841	6.18	7.85	2.80	129	0.20	0.25	0.50
1⅛	1.276	755	1.14	1.45	1.20	543	3.99	5.09	2.26	199	0.31	0.40	0.63
1⅛	1.280	1,717	2.58	3.30	1.82	53	0.39	0.50	0.71	173	0.27	0.35	0.59
1⅘	1.285	1,565	2.36	3.03	1.74	29	0.21	0.27	0.52	576	0.90	1.16	1.08
1⅗	1.291	557	0.84	1.08	1.04	63	0.46	0.59	0.77	782	1.23	1.59	1.26
1⅖	1.297	663	1.00	1.30	1.14	119	0.88	1.14	1.07	758	1.19	1.54	1.24
1⅕	1.304	1,233	1.86	2.43	1.56	186	1.37	1.79	1.34	2,007	3.15	4.11	2.03
1⅘	1.311	1,254	1.89	2.48	1.57	501	3.68	4.82	2.20	3,458	5.42	7.37	2.71
1⅗	1.318	1,519	2.29	3.02	1.74	152	1.12	1.48	1.22	3,984	6.23	8.21	2.87
1⅖	1.325	1,545	2.32	3.07	1.75	30	0.22	0.29	0.54	1,004	1.57	2.08	1.44
1⅓	1.327	1,217	1.83	2.43	1.56	7	0.05	0.07	0.26	389	0.56	0.74	0.86
1⅛	1.332	804	1.21	1.61	1.27	7	0.05	0.07	0.26	40	0.06	0.08	0.28
1⅛	1.336	439	0.66	0.88	0.94	6	0.04	0.05	0.22	708	1.11	1.48	1.22
1⅘	1.341	818	1.23	1.65	1.28	11	0.08	0.11	0.33	1,500	2.35	3.15	1.77
1⅗	1.346	1,845	2.78	3.74	1.93	6	0.04	0.05	0.22	1,700	2.67	3.59	1.89
1⅖	1.351	3,342	5.03	6.79	2.61	113	0.83	1.12	1.06	3,023	4.75	6.42	2.53
1⅕	1.356	4,070	6.13	8.31	2.88	326	2.39	3.24	1.80	650	1.02	1.38	1.17
1⅘	1.361	3,444	5.18	7.05	2.66	644	4.73	6.44	2.54	258	0.41	0.56	0.75
1⅗	1.367	1,577	2.37	3.24	1.80	706	5.19	7.09	2.66	6	0.01	0.01	0.10
1⅖	1.373	727	1.10	1.51	1.23	353	2.59	3.56	1.89	23	0.04	0.05	0.22
1⅓	1.379	334	0.50	0.69	0.83	97	0.71	0.98	0.99	98	0.15	0.21	0.46
1⅛	1.385	72	0.11	0.15	0.39	42	0.31	0.43	0.66	10	0.02	0.03	0.17
1⅛	1.391	8	0.01	0.01	0.10	35	0.26	0.36	0.60	56	0.09	0.13	0.36
1⅘	1.397	384	0.58	0.81	0.90	57	0.42	0.59	0.77	487	0.76	1.06	1.03
1⅗	1.404	1,816	2.74	3.85	1.96	144	1.06	1.49	1.22	1,621	2.53	3.58	1.89

		Pacific coast				British Isles				The Punjab			
Mean I...		664.5				136.0				636.9			
P	F	I	H	H'	A	I	H	H'	A	I	H	H'	A
1⅘	1.410	2,006	3.02	4.26	2.06	59	0.43	0.61	0.78	2,460	4.18	5.89	2.43
1⅗	1.417	1,420	2.14	3.07	1.75	34	0.25	0.35	0.59	3,830	6.01	8.52	2.92
1⅖	1.424	107	0.16	0.23	0.48	513	3.77	5.37	2.32	3,670	5.76	8.21	2.87
1⅕	1.431	245	0.37	0.53	0.73	1,137	8.35	11.95	3.46	2,104	3.30	4.72	2.17
1⅘	1.438	656	0.98	1.41	1.19	748	5.50	7.91	2.81	709	1.11	1.60	1.26
1⅗	1.446	232	0.35	0.51	0.71	121	0.89	1.29	1.14	901	1.41	2.04	1.43
1⅖	1.454	830	1.33	1.93	1.39	28	0.21	0.31	0.56	2,565	4.03	5.86	2.42
1⅓	1.462	3,900	5.88	8.60	2.93	112	0.82	1.20	1.10	4,513	7.08	10.36	3.22
1⅔	1.469	5,675	8.55	12.56	3.54	43	0.32	0.47	0.67	4,315	6.78	9.96	3.16
1⅗	1.475	4,180	6.30	9.30	3.05	98	0.72	1.06	1.03	2,924	4.59	6.77	2.60
1⅖	1.481	1,871	2.82	4.18	2.04	272	2.00	2.96	1.72	1,705	2.67	3.93	1.99
1⅕	1.488	310	0.47	0.70	0.84	352	2.59	3.85	1.96	694	1.09	1.62	1.27
1⅓	1.494	154	0.23	0.34	0.58	261	1.92	2.87	1.69	930	1.46	2.18	1.48
1⅓	1.501	350	0.53	0.80	0.99	120	0.88	1.32	1.15	1,120	1.76	2.64	1.62
1⅔	1.508	267	0.40	0.60	0.77	76	0.56	0.84	0.92	802	1.26	1.90	1.38
1⅗	1.515	212	0.32	0.48	0.69	55	0.40	0.61	0.78	398	0.62	0.94	0.97
1⅖	1.522	416	0.63	0.96	0.98	50	0.37	0.56	0.75	122	0.19	0.29	0.54
1⅕	1.529	464	0.70	1.07	1.03	247	1.82	2.78	1.67	193	0.30	0.46	0.68
1⅓	1.536	694	1.05	1.61	1.27	355	2.61	4.01	2.00	227	0.36	0.55	0.74
1⅔	1.544	1,059	2.40	3.71	1.93	229	1.69	2.61	1.62	199	0.31	0.48	0.69
1⅗	1.552	2,236	3.37	5.23	2.29	41	0.30	0.47	0.69	4	0.01	0.02	0.14
1⅖	1.560	3,166	4.77	7.44	2.73	24	0.18	0.28	0.53	295	0.46	0.72	0.85
1⅕	1.568	2,998	4.52	7.08	2.66	82	0.60	0.94	0.97	698	1.09	1.71	1.31
1⅙	1.577	1,966	2.96	4.67	2.16	30	0.22	0.35	0.59	1,255	1.97	3.11	1.76
1⅔	1.585	602	0.91	1.44	1.20	76	0.56	0.89	0.94	1,520	2.39	3.79	1.95
1⅗	1.594	418	0.63	1.00	1.00	379	2.79	4.45	2.11	1,696	2.66	4.24	2.06
1⅖	1.603	172	0.26	0.42	0.65	576	4.24	6.80	2.61	886	1.39	2.23	1.49
1⅕	1.612	530	0.80	1.29	1.14	436	3.21	5.17	2.27	156	0.24	0.39	0.62
1⅔	1.621	2,990	4.50	7.30	2.70	226	1.66	2.69	1.64	164	0.26	0.42	0.65
1⅗	1.631	5,430	8.18	13.34	3.65	17	0.12	0.20	0.45	1,550	2.43	3.96	1.99
1⅖	1.641	5,025	7.57	12.42	3.52	50	0.37	0.61	0.78	3,830	6.01	9.86	3.14
1⅕	1.652	3,220	4.85	8.02	2.83	325	2.39	3.95	1.99	5,078	7.98	13.19	3.63
1⅓	1.663	643	0.97	1.61	1.27	578	4.25	7.07	2.66	4,380	6.88	11.44	3.38
1⅔	1.674	374	0.56	0.94	0.97	560	4.12	6.90	2.63	3,745	5.88	9.85	3.14
1⅗	1.685	955	1.44	2.42	1.56	214	1.57	2.65	1.63	835	1.31	2.21	1.49
1⅖	1.697	2,380	3.59	6.09	2.47	102	0.75	1.27	1.13	98	0.15	0.25	0.50
1⅕	1.709	3,770	5.68	9.71	3.12	146	1.07	1.83	1.35	56	0.09	0.15	0.39
1⅓	1.721	2,614	3.93	6.76	2.60	181	1.33	2.29	1.51	389	0.61	1.05	1.02
1⅔	1.733	836	1.26	2.18	1.48	49	0.36	0.62	0.79	411	0.65	1.13	1.06
1⅗	1.746	110	0.17	0.30	0.55	6	0.04	0.07	0.26	812	1.27	2.22	1.49
1⅖	1.754	154	0.23	0.40	0.63	37	0.27	0.47	0.69	1,043	1.64	2.88	1.70
1⅕	1.763	194	0.29	0.51	0.71	230	1.69	2.96	1.73	628	0.99	1.75	1.32
1⅓	1.772	147	0.22	0.39	0.62	432	3.17	5.62	2.37	433	0.68	1.20	1.10
1⅔	1.781	174	0.26	0.46	0.68	484	3.56	6.34	2.52	360	0.56	1.00	1.00
1⅗	1.790	261	0.39	0.70	0.84	342	2.51	4.49	2.12	644	1.01	1.81	1.35
1⅖	1.800	521	0.79	1.42	1.19	146	1.07	1.93	1.39	1,071	1.68	3.03	1.74
1⅕	1.810	486	0.73	1.32	1.19	112	0.82	1.48	1.22	1,294	2.03	3.78	1.94
1⅓	1.820	263	0.40	0.73	0.85	152	1.12	2.04	1.43	1,770	2.78	5.06	2.25
1⅔	1.828	134	0.20	0.37	0.61	166	1.22	2.23	1.49	1,685	2.65	4.84	2.20
1⅗	1.836	322	0.48	0.88	0.94	102	0.75	1.38	1.17	1,378	2.16	3.97	1.99
1⅖	1.848	1,129	1.70	3.14	1.77	60	0.44	0.81	0.90	472	0.74	1.37	1.17
1⅕	1.861	492	0.74	1.38	1.17	77	0.57	1.06	1.03	207	0.32	0.60	0.77
1⅓	1.872	440	0.66	1.24	1.11	50	0.37	0.69	0.83	724	1.14	2.14	1.46
1⅔	1.883	1,355	2.04	3.84	1.93	159	1.17	2.20	1.48	1,895	2.97	5.59	2.36
1⅗	1.895	2,880	4.34	8.22	2.87	367	2.70	5.12	2.26	3,052	4.79	9.08	3.01
1⅛	1.907	3,716	5.63	10.73	3.28	754	5.54	10.56	3.25	2,380	3.74	7.14	2.67

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PAPERS ON THE REALITY OF METEROLOGICAL PERIODICITIES

I. INTRODUCTORY NOTE

By C. F. MARVIN

It is interesting to present in the accompanying articles the opposing views of two prominent hydrologic engineers concerning periodicities in rainfall and stream flow.

The perplexing question of the underlying laws controlling meteorological sequences can not be disposed of by simple theories. Deductions must follow observational data and be consistent with known physical laws.

Constancy in consecutive values of meteorological data is an unknown characteristic, whether we examine individual values of such groups as monthly, seasonal, annual, or lustrum means, etc. The same is true with data treated by smoothing formulæ. Ceaseless fluctuations in consecutive values is the outstanding feature of the time function of meteorological data. We can not, in advance of suitable summaries of actual observations, safely proceed on the theory that more or less striking fluctuations will not be found in data, even for the entire globe, if appropriate units and summaries are employed.

Every investigation of meteorological sequences encounters at the outset the question: Is the order of succession of values fortuitous and lawless, or is it systematic and controlled, in some slight degree at least?

Mr. Clough[1] has summarized the greater part of what is known of the mathematical characteristics of purely fortuitous data as compared with those displayed by meteorological statistics. The latter, when tested by one or more criteria, rarely fail to show that the order of succession of the natural data differs more or less from a perfectly fortuitous one. This would doubtless prove to be the case with most of the sequences shown by Mr. Streiff, as well as those of Mr. Grunsky. Such being the case, the data call for appropriate interpretation. However, statistical evidence that the order of succession in California rainfall is controlled does not imply that Mr. Streiff's paricular interpretation is necessarily confirmed. If we say the features are periodic, the word period must be very liberally defined to signify recurrences at intervals which may differ in length at least 100% in extreme cases and with variations in amplitude also. No better appellation than "periodicity" has yet been proposed for these irregular recurrences, and a good deal of skepticism about meteorological periodicities is aroused when the sense in which this word is necessarily used is narrowly construed.

The recurrent features develop with greater or less regularity in all classes of data and undoubtedly call for segregation, study, and interpretation.

The Brückner period (25 to 35 years) is so long and so obscure that observations for 150 to 200 years are absolutely necessary to even fairly demonstrate its reality. Nevertheless, evidence of its presence in shorter records can not be entirely disregarded.

A partial harmonic analysis of the California rainfall percentages from 1851 to 1926 gives for the San Francisco and Sacramento values a large, well-defined secular trend, characterized by moderate values after 1850, rising to sustained maximum ratios during the eighties, followed by low minimum values about 1916 and tending to higher values at the present time. This secular trend is quite accurately represented by a 70 or 80 year period, but it would be folly to claim that such a period is real; it is simply a secular trend. The amplitude of any short period around 30 to 35 years is quite insignificant in the central California data, but a period of 20 to 26 years has a relatively larger amplitude of about 15 per cent above or below normal.

The San Diego values are in close accord with those of central California up to 1907, but remained generally above normal thereafter. The secular trend is, therefore, missing. The amplitude of a 36-year period comes out below 15% with crests at 1881 and 1917, whereas the 24-year period has about the same amplitude, the two periods in this short record being mathematically independent.

These results indicate how different and uncertain conclusions are when they are drawn from records of inadequate length.

[1] MONTHLY WEATHER REVIEW, March, 1921, 49: 124–132.

II. THE IMPROBABILITY OF RAINFALL CYCLES

By C. E. GRUNSKY, Consulting Civil Engineer

[San Francisco, Calif.]

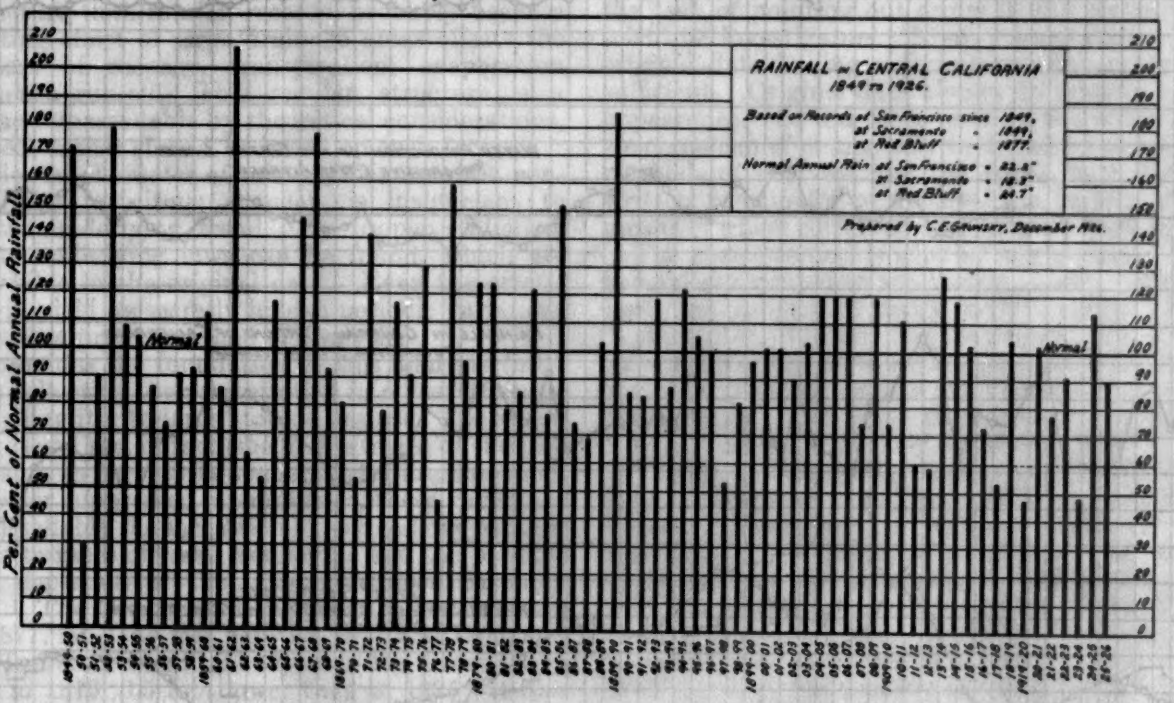
There has just come to the writer's attention the article by Mr. A. Streiff "On the investigation of cycles and the relation of the Brückner and the solar cycle," published in the MONTHLY WEATHER REVIEW of July, 1926. His conclusions are by no means convincing. The fact is so well known that the annual precipitation on the surface of the earth, taken in its full extent, may be accepted as equal to annual evaporation—if transpiration be included in evaporation in the sense as here used—and that the amount of heat which reaches the earth from the sun year by year varies within such narrow limits, that aggregate annual evaporation, and consequently precipitation, on the entire surface of land and water, when one year is compared with another, may be accepted as constant in amount. There must, therefore, be a more or less complementary relation between those regions in which there is a deficiency of rain in any year (compared with normal) and those other regions in which there is an excess. Moreover, the complementary regions are not persistent in location or area. There is never-ending change, much more likely to be caused by slight variation in ocean currents and ocean temperatures than by activity in the solar chromosphere. Rainfall for this reason is not at all likely to respond to or to harmonize with cycles of solar or planetary influence. This is partially true also of tree rings when they are used as indices to climatic conditions. The growth of the tree is only occasionally, as in parts of California and only when suitably located, an index to droughts and to wet years.

An illustration or two may suffice to show how little dependence can be placed on rainfall and stream-flow records for the deducing of cycles and to show that careless use thereof must always throw doubt upon resultant conclusions. In noting average rainfall conditions throughout California the United States Weather Bureau

quite properly makes use of 12 records widely scattered. The rainfall at Red Bluff and at other stations is grouped with the rainfall at San Diego to obtain averages, even though it is well known that, particularly in the winters of the dry type in this State, when our main LOWS enter from the ocean far to the north of Oregon and produce only light rain in northern and central California, there may be heavy rainfall at San Diego resulting from entirely unrelated southern storm conditions. As examples of the lack of consistent correlation, the following comparison of the rainfall in terms of the annual normal in the vicinity of Los Angeles with that in central portions of California, all of which show wide departure from the ordinary relation, may be cited. This comparison is based on the rainfall records at three stations, Los Angeles, San Bernardino, and Santa Barbara for rain in the vicinity of Los Angeles and on San Francisco, Sacramento, and Red Bluff for rain in central California.

hopelessness of using Pacific slope rainfall records as a basis for the determination of cycles from records even as long as 80 years.

The rainfall is expressed in this diagram in percentage of normal. The figures given as the averages can be applied with confidence to any portion of central California for which the normal rainfall is known. The percentage of normal for the individual years at the three selected stations are in such remarkably close agreement that the composite values shown in the diagram may be accepted as a better indication of rain conditions which have produced run-off than any single station record. It will be noted that in central California from 1849 to 1890 there were quite a few rain years (July 1 to the following June 30) in which precipitation exceeded normal by 50 to 100 per cent. There have been no such years since 1889–1890; and yet they must be looked forward to with certainty as to their occurrence at some time in


RAINFALL in CENTRAL CALIFORNIA
1849 to 1926.
Based on Records of San Francisco since 1849,
at Sacramento " 1849,
at Red Bluff " 1877.
Normal Annual Rain at San Francisco = 22.8"
at Sacramento = 18.3"
at Red Bluff = 24.7"
Prepared by C.E. Grunsky, December 1926.
Per Cent of Normal Annual Rainfall
Normal
Normal

Season	Percentage of normal in—		Season	Percentage of normal in—	
	Central California	Near Los Angeles		Central California	Near Los Angeles
1850–51	30	86	1895–96	105	60
1859–60	68	113	1903–4	103	60
1864–65	117	87	1915–16	102	143
1871–72	141	69	1917–18	53	98
1880–81	124	85	1919–20	47	95
1883–84	122	226	1921–22	77	133
1887–88	69	107			

Mr. Streiff, in the article above referred to, in discussing cycles combines the San Diego record with station records as far north as The Dalles and Astoria, thereby invalidating in some measure the sequence of wet, of normal, and of dry years, which the northerly records considered alone would indicate.

On a diagram (fig. 1) herewith submitted there is shown the rainfall in central California based on the three dependable records, San Francisco, Sacramento, and Red Bluff, a mere inspection of which will show the

the future. No one can foretell when the next very wet climatic year or group of wet years will occur. There is no possibility of any forecast thereof by the use of sun-spot or any other cycles.

That the varying radioactivity of the sun and its periodic extreme conditions as manifested by minimum and maximum sun-spot frequency is very likely to influence plant life, and therefore to have an effect on the growth of trees, appears clear, but conclusions as to rainfall should not, as already intimated, be drawn with too much confidence from the appearance of tree rings.

The use of stream flow in a study of meteorological cycles introduces new factors of uncertainty. The stream flow is not definitely related to the rainfall. It is well known that in the West, for example, the distribution of the rain to the several months of the year, or, better, its amount during individual rain storms and the sequence of the several storms of the year, influences greatly the amount of run-off. Any established relation between between rain and run-off is only a probability, from which wide departure must be expected. A new source of error

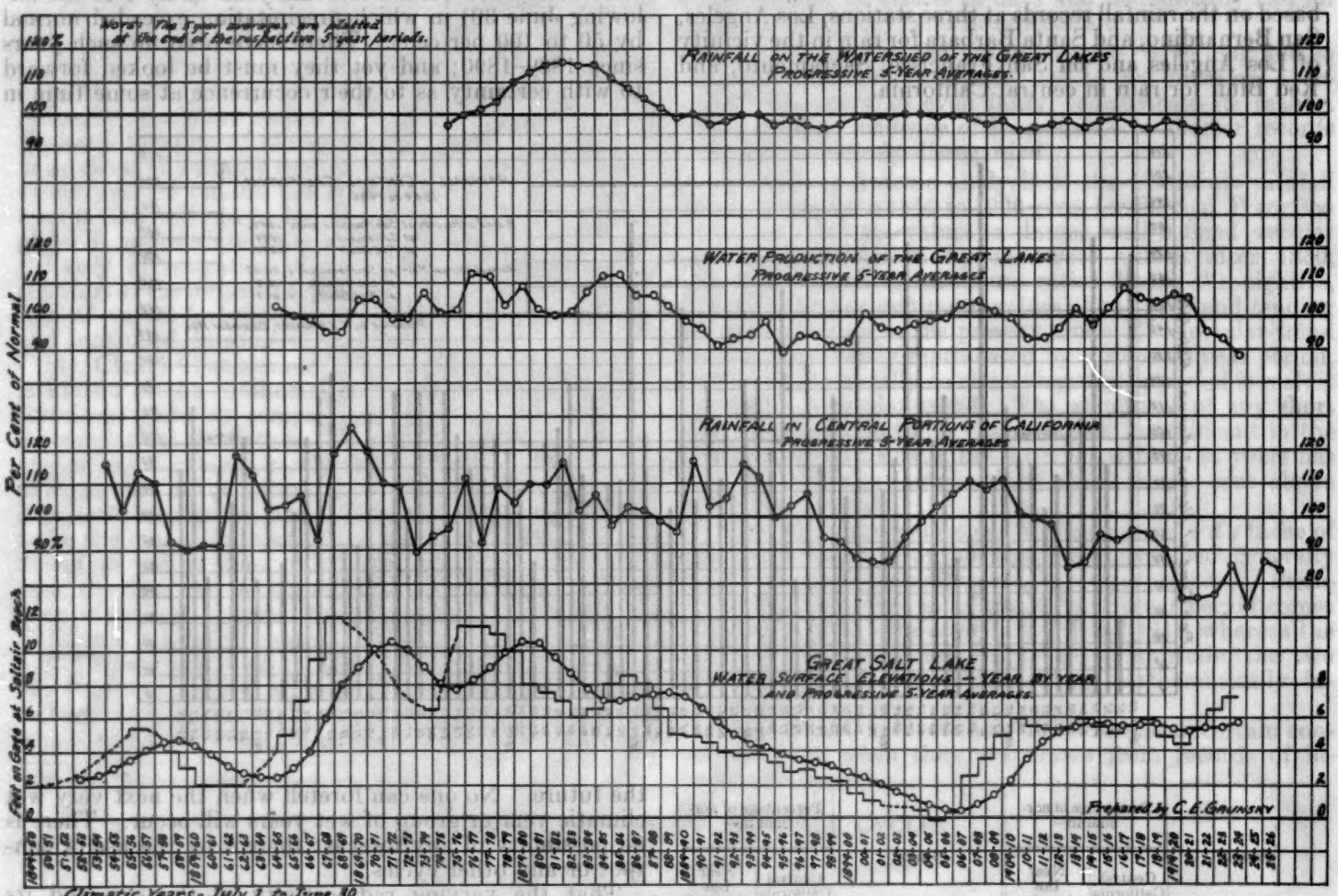
is therefore introduced when stream flow is used in the study of weather cycles. Furthermore, for only very few streams are dependable records available for long-time periods. Then, again, in such cases as the flow of Niagara River and the elevation of Lake Ontario there are other disturbing factors. Evaporation from the Great Lakes has a relatively wide range and directly modifies the outflow of water from the lakes, disturbing the correlation of rainfall and water production. Below Lake Ontario is the Cut Dam across one of the branches of the St. Lawrence. The lake elevation fluctuates within narrow limits; the dam affects the lake stage more or less. There should at least be a separation of this lake record into two portions, one before the construction of the dam and the other subsequent to its construction. Other human activities have affected the stages of the Great Lakes and the outflow from them, all of which should be taken into account in determining stream flow or water production when such data are to be used in the manner of Mr. Streiff's paper.

It is quite probable that all efforts thus far made to find long-term cycles in the varying annual precipitation or in the stream flow are premature, even as it may be considered certain that variations in rain corresponding to one-third and other fractions of the solar cycle—as suggested by some students of meteorology—are mere accidents and can never be conclusively established.

In further explanation of the futility of correlating precipitation and sun-spot frequency and as basic data for students of the subject, a second diagram has been prepared showing four curves as follows: The progressive five-year average amounts of rain in terms of normal annual at the Great Lakes; the progressive five-year average water production of the Great Lakes, also expressed in percentage of normal; the stages of the Great Salt Lake, Utah; and the progressive five-year average amount of precipitation in central California.

The determination of precipitation at the Great Lakes as shown in this diagram applies to the entire watershed or drainage basin tributary to the Niagara River. It is probably the most dependable determination ever attempted for this region, being based on the records in a 53-year period, 1871 to 1923, at 47 stations in the United States and 7 in Canada, all suitably weighted to determine the normals for the 53-year period, which were thereupon used in calculating the annual percentages of normal. This compilation was made several years ago by the writer for the Sanitary District of Chicago in connection with a study of rainfall and of water production in the Great Lakes Basin.

The shapes of the curves on this diagram indicate at once that longer time is needed to prove the existence of any notable cycle, or, perhaps, to establish conclusively, as the writer believes, that none will ever be found.


Note: The 5-year averages are plotted at the end of the respective 5-year periods.
RAINFALL ON THE WATERSHED OF THE GREAT LAKES
PROGRESSIVE 5-YEAR AVERAGES.
WATER PRODUCTION OF THE GREAT LAKES
PROGRESSIVE 5-YEAR AVERAGES
RAINFALL IN CENTRAL PORTIONS OF CALIFORNIA
PROGRESSIVE 5-YEAR AVERAGES
GREAT SALT LAKE
WATER SURFACE ELEVATIONS - YEAR BY YEAR
AND PROGRESSIVE 5-YEAR AVERAGES.
Per Cent of Normal
Feet above Sea Level
Prepared by C. E. Grunsky
Climatic Years - July 1 to June 30

III. SUNSPOTS AND RAINFALL

By ABRAHAM STREIFF, Consulting Engineer
[Jackson, Mich.]

That original data of rainfall present an irregular and fortuitous appearance is well known. Rainstorms passing at a short distance from a dry observing station, erratic distribution of rain in cyclones, and the multitude of physical and geographical causes varying and influencing rainfall are well known. In central Texas, September 7 to 11, 1921, 4 inches of rain fell in 35 hours in one place and 23.98 inches was recorded only 18 miles away—a whole year's supply in three days.

This accidental distribution is a generally known fact. If, however, larger values of the elements of time and space are selected, a different picture appears. The writer has pointed out that the rain gage is virtually but a point in space and that run-off records do have a far more regular structure than rainfall records, probably because the integrating effect of large drainage areas offsets the added factors of seepage, transpiration, evaporation which influence run-off. This regular structure is a statistical fact, unassailable by theoretical considerations, which, indeed, rather should be based on such facts.

The accidental character of rain-gage data, while containing a large fortuitous element, is insufficient to obliterate the underlying trend. By proper statistical methods the underlying laws can be found, which are entirely invisible in the original data. Even the erratic rain gage will yield its secretly hidden periodic variations if treated with a proper method of analysis.

Nature provides the foundation of this analysis (integration) by collecting the precipitation in a vast drainage area and leading it into large storage basins. The variations in lake level are, in fact, the first integral of the precipitation, and, as hereby the longer cycles are increased, and the shorter suppressed in amplitude, these variations reveal unmistakably the succession of wet and dry periods. The famous terraces of Lake Bonneville and the periodic filling and depletion of the lake have been carefully studied (*1*). The Great Salt Lake rose 9½ feet between 1860 and 1877, fell 11½ feet between 1877 and 1905, and has risen 7 feet since then. The level in the Great Lakes was lowest in 1819, 0.5 foot lower than in 1925; it rose 6.6 feet from 1819 to 1838; both record stages occurring long before the Chicago drainage canal or the Soo Locks or the Gut Dam were made or the Detroit River was dredged (*2*).

Presumably, then, there is no discussion as to the existence of such periodic variations, the question rather being *to what extent* such variations are apparently fortuitous or, on the other hand, seem to be subject to cross-identification with other known phenomena of nature.

In the tangled skein of natural phenomena indications of periodic recurrences have long since been found, and their correlation has been a subject of prolonged and searching investigation. The periodic variations of rainfall have been carefully studied by Hellman (*3*), Brückner (*4*), Jenkin (*5*), Moore (*6*), Brooks (*7*), Abbé Gabriel (*8*), Schokalsky (*9*), Hann (*10*), Stockman (*11*), and many others. A discussion of such changes may be found in the works on climatology or physical geography, as Huntington and Visher (*12*) or Élisée Reclus (*13*). They are an accepted fact and can no longer be doubted.

It is now 37 years ago that Professor Eduard Brückner, geographer at the University of Berne, Switzerland, published his famous work, "Klimaschwankungen seit 1700." Herein the variations of rainfall are studied by means of meteorological records and also through the historical records of the variations of lake levels, which, for many lakes and inland seas of the old world, reach far back into history. Brückner concluded, from these and many other elaborate statistics, that three variable cycles in climate exist, superimposed on each other, the shortest of which is now called the "Brückner cycle."

Such studies are being pursued up to the present day; one of the latest publications on lake levels as a means of forecasting rainfall being the study of Axel Wallén, "Zwölf Jahre langfristiger Prognosen von Niederschlag und Wasserstand" (*19*).

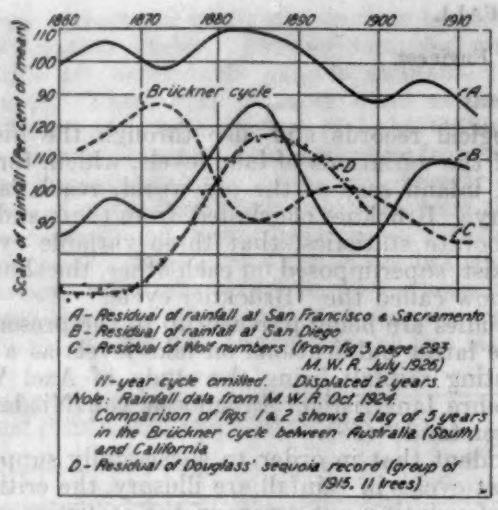
It is evident that in order to successfully support the theory that cycles in rainfall are illusory, the critic faces the task of pointing out errors in the statistics of these scientific investigators. Mere presentation of curves of original data having a fortuitous appearance seems insufficient. Original data always do present a fortuitous appearance. So did those used by the writer; the cyclic elements can of course only be found by means of proper methods of analysis, and the article here discussed was written principally to demonstrate certain methods by means of which correlations apparently were easily found.

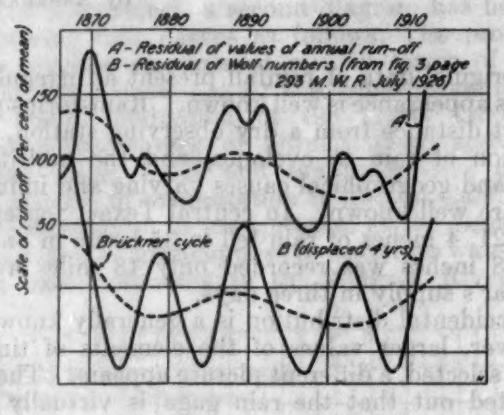
The next question is whether the cycles in rainfall are in any way related to the Wolf numbers. This, too, has been the subject of many investigations. Sir Gilbert Walker (*14*), Buchan (*15*), Schreiber (*16*), Koenig (*17*), have studied the matter carefully. C. E. P. Brooks (*18*) published striking graphs for Victoria Nyanza in equatorial Africa which show the correlation clearly. These studies deal with the 11-year cycle.

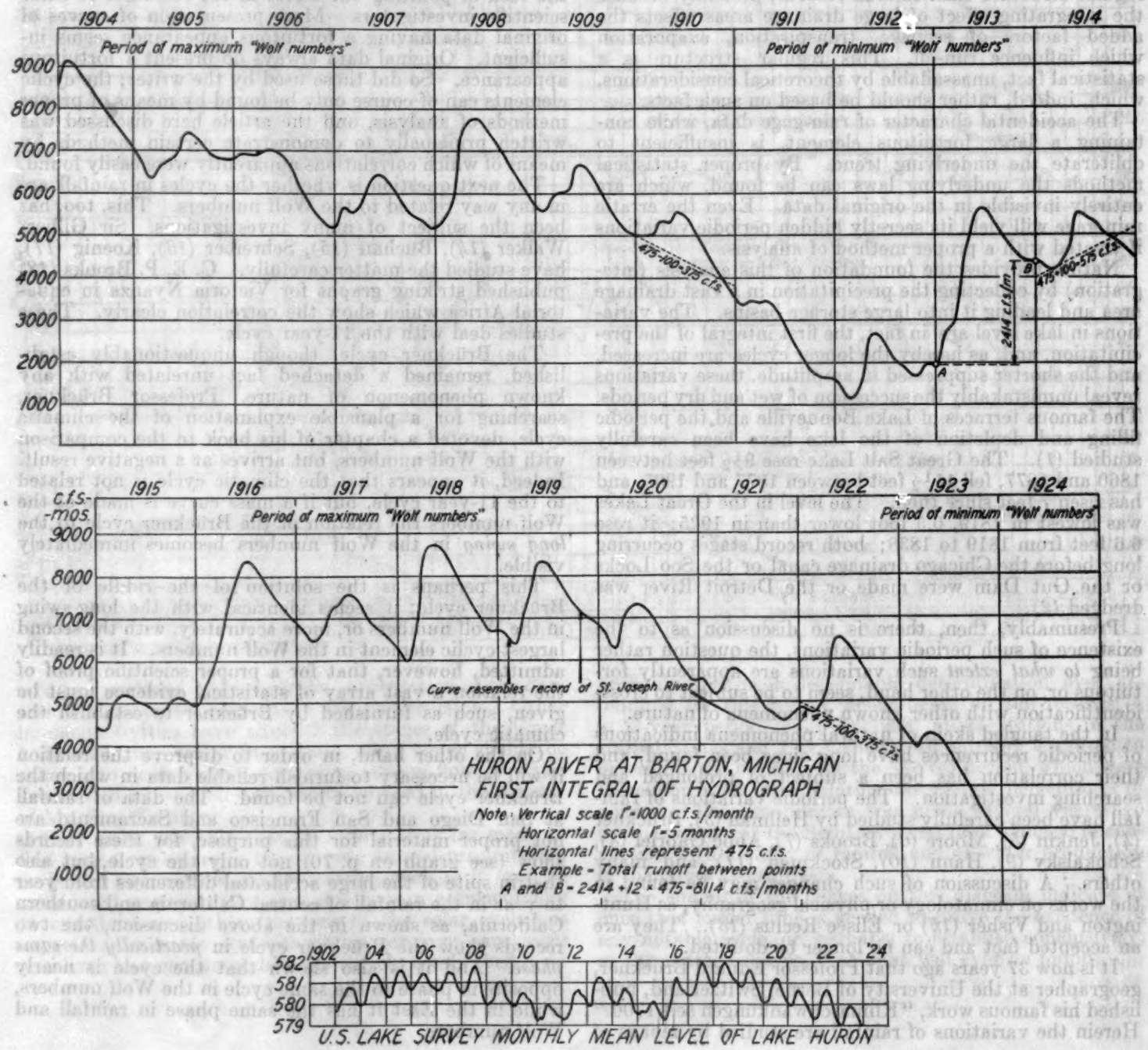
The Brückner cycle, though unquestionably established, remained a detached fact unrelated with any known phenomenon of nature. Professor Brückner, searching for a plausible explanation of the climatic cycle, devoted a chapter of his book to the comparison with the Wolf numbers, but arrives at a negative result. Indeed, it appears that the climatic cycle is not related to the 11-year cycle, but if a mass curve is made of the Wolf numbers the relation of the Brückner cycle to the *long swing* in the Wolf numbers becomes immediately visible.

This perhaps is the solution of the riddle of the Brückner cycle; it seems identical with the long swing in the Wolf numbers or, more accurately, with the second largest cyclic element in the Wolf numbers. It is readily admitted, however, that for a proper scientific proof of the relation a vast array of statistical evidence must be given, such as furnished by Brückner to establish the climatic cycle.

On the other hand, in order to disprove the relation it will be necessary to furnish reliable data in which the Brückner cycle can not be found. The data of rainfall at San Diego and San Francisco and Sacramento are not proper material for this purpose, for these records show (see graph on p. 70) not only the cycle, but also that in spite of the large accidental differences from year to year in the rainfall of central California and southern California, as shown in the above discussion, the two records show the Brückner cycle in *practically the same phase*. And it is also shown that the cycle is nearly opposite in phase to the same cycle in the Wolf numbers, while in the East it has the same phase in rainfall and Wolf numbers.


1860
1870
1880
1890
1900
1910
Scale of rainfall (Per cent of mean)
Brückner cycle
A
B
C
D
A - Residual of rainfall at San Francisco & Sacramento
B - Residual of rainfall at San Diego
C - Residual of Wolf numbers (from fig 3 page 293 M. W. R. July 1926)
11-year cycle omitted. Displaced 2 years.
Note: Rainfall data from M. W. R. Oct. 1924.
Comparison of figs 1 & 2 shows a lag of 3 years in the Brückner cycle between Australia (South) and California
D - Residual of Douglass' sequoia record (group of 1915, 11 trees)


1870
1880
1890
1900
1910
A - Residual of values of annual run-off
B - Residual of Wolf numbers (from fig 3 page 293 M. W. R. July 1926)
Scale of run-off (Per cent of mean)
Brückner cycle
B (displaced 4 yrs)
A


1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
Period of maximum "Wolf numbers"
Period of minimum "Wolf numbers"
475+100=575 c.f.s.
2414 c.f.s/m
A
B
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
c.f.s.-mos.
Curve resembles record of St. Joseph River
HURON RIVER AT BARTON, MICHIGAN
FIRST INTEGRAL OF HYDROGRAPH
Note: Vertical scale 1"=1000 c.f.s./month
Horizontal scale 1"=5 months
Horizontal lines represent 475 c.f.s.
Example - Total runoff between points
A and B = 2414 + 12 × 475 = 8114 c.f.s./months

1902
'04
'06
'08
'10
'12
'14
'16
'18
'20
'22
'24
U.S. LAKE SURVEY MONTHLY MEAN LEVEL OF LAKE HURON

It may further be seen that the variation due to the Brückner cycle has considerable amplitude, although the curves shown are residuals and do not give the full amplitude, the amplitude of the residual at San Diego is not less than 35% of the mean for the epoch shown. Also, this residual (San Diego) seems to coincide with the residual of Douglass' sequoia record (1915, 11 trees).

Other investigators have found a relation between San Diego rainfall and sun spots. Mr. John R. Freeman writes: "Three years ago, when studying on the water supply for the city of San Diego, I became perfectly convinced that in that region there was a connection between the Wolf sun-spot cycle and the great floods which have come, about once in 10 years, ever since the earliest days of the Spanish missions."

Taking another quarter of the globe, the writer also presents (p. 70, top) a residual of the run-off of the Murray River, one of the largest drainage basins of Australia, the record of which was obtained through the courtesy of Mr. Elwood Mead. The relation is here again visible, and the Brückner cycle in run-off differs about six years in phase between South Australia and California.

For the Middle West the relation with the Wolf numbers is plainly visible. The mass curve of the Huron River at Barton, Mich., obtained by the writer through the courtesy of Mr. Gardner S. Williams, shows the relation with the 11-year cycle; also the secondary maximum at sun-spot minimum already pointed out by Hann (*21*). This is still better visible in the level of Lake Huron, the fall in level after 1913 (sun-spot minimum) being accentuated probably by evaporation and not so plainly visible in the river record.

Through all ages and in various regions of the globe the relation is traceable. G. del Valle (*22*) presents interesting graphs of the long rainfall record of the ancient university city of Padua in the Po Valley and the high-water stages of the River Nile from 1725 to date, which reveal immediately the agreement with the two long swings of the "secular cycle." (Fig. 1, p. 292, MONTHLY WEATHER REVIEW, July, 1926.) The historic record of the high and low water stages of the Nile, A. D. 642 to 1451, given by Aboul Mahasin in the "Mémoires de l'Institute d'Egypte, 1923," covering a period of eight centuries, unmistakably shows the tendency of run-off to follow a periodic variation, having, according to Del Valle, a period of 210 years. Unfortunately the record of the Wolf numbers is too short to permit a comparison.

It seems quite possible that the total yearly rainfall taken over the whole globe should vary from year to year in spite of the nearly constant amount of heat received yearly from the sun. Evaporation is dependent on humidity as well as temperature, and on other factors as well—as, for instance, exposed surface area and wind velocity. Evaporation will take place in a thermally isolated vessel without supply of heat, thereby lowering the temperature. The latent heat is always restored to the atmosphere upon condensation, and possibly is used repeatedly, as in industrial multiple evaporators. Perhaps the findings of Doctor Dorno, tending to prove (*20*) increased atmospheric condensation (circumpolarer Gegenschein) with increasing sun spots, furnish a plausible explanation of the relation between rainfall and sun spots. However, the relation of Wolf numbers and terrestrial phenomena is, as Doctor Marvin expresses it, full of interminable perplexities, and undoubtedly contains many physical elements thus far wholly unexplained.

Statistical evidence can always be classified as merely accidental until it becomes available in such large quantity that the reality of the relation can no longer be doubted. On the other hand, unless reliable records are offered in which this relation can not be found by analysis, it seems unfounded to regard the mere fortuitous appearance of the original data as sufficient proof of the absence of a relation between sun spots and rainfall.

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LAG OF THERMOMETERS AND THERMOGRAPHS FOR AIRCRAFT[1]

By H. B. HENRICKSON and W. G. BROMBACHER

[Bureau of Standards, U. S. Department of Commerce]

The time lag of thermometers used to measure air temperatures may be of considerable importance in cases where the temperature to be measured may be changing rapidly. Data on the time lag of various types of thermometers designed for installation on aircraft for the measurement of air temperatures would therefore be of value in the design and selection of instruments for such measurements. Measurements were made of the time lags of a representative group of instruments selected from those available in the laboratory. This work was undertaken in the course of the development of aircraft thermometers for the National Advisory Committee for Aeronautics and the Bureau of Aeronautics, United States Navy, and acknowledgment is here made of their financial assistance.

It is known that the lag is dependent upon the velocity of the air stream to which the temperature element is exposed. The values reported here were for an exposure of the element in an improvised wind tunnel in which a maximum velocity of 17 miles per hour could be maintained. The data are therefore chiefly of value in determining the relative lags of the various instruments, but it is also possible from available data to estimate the order of magnitude of the various lags at customary flying speeds.

A detailed discussion of the question of thermometric lag is given in a paper by Harper.[2] In general, a problem of thermometric lag can be treated with sufficient accuracy by assuming that Newton's law of cooling applies—that is, that the rate of change in the temperature of the thermometer is proportional to the difference between this temperature and that of the surrounding medium. If T be the indication (temperature) of the thermometer, t the time and U the temperature of the medium, Newton's law is expressed by the equation:

$$\frac{dT}{dt}=\frac{1}{\lambda}(U-T) \qquad (1)$$

The equation is written so as to make λ a positive constant, for if λ is positive, and U is higher than T, dT/dt will also be positive. The constant of proportionality is written in the form $1/\lambda$ for convenience, because when so written λ can be interpreted in a simple and useful manner. Two such interpretations are given by Harper (p. 662):

(1) If a thermometer has been immersed for a long time in a bath whose temperature is rising at uniform rate, λ is the number of seconds between the time when the bath attains any given temperature and the time when the thermometer indicates this temperature. In other words, it is the number of seconds the thermometer "lags" behind such a temperature.

(2) If a thermometer be plunged into a bath maintained at a constant temperature (the thermometer being initially at a different temperature), λ is the number of seconds in which the difference between the thermometer reading and the bath temperature is reduced to e^{-1} times its initial value.

e is the base of natural logarithms and equals 2.718.

Definition (1) is of especial importance in aeronautics. In the performance testing of aircraft a maximum rate of climb is usually maintained, and therefore the temperature of the free air in the vicinity of the aircraft is decreasing. Assuming the maintenance of a steady rate of climb of the aircraft, the following relation will hold when conditions become steady:

$$T-U=-r\lambda \qquad (2)$$

where U is the air temperature, T the indication of the thermometer, r the rate of change of free air temperature per second and λ the lag of the thermometer. Thus, for example, assume that an airplane climbs at a rate of 3,000 feet per minute in an atmosphere in which the average conditions of free-air temperature exist. The value of r is then approximately 0.1° C. per second. Further, assume that the lag, λ, of the thermometer when exposed to the free air moving at the air speed of the airplane is 10 seconds. Inserting these values in equation (1) it is seen that $(T-U)$ equals 1° C., which means that the indication of the thermometer lags 1° C. behind the free-air temperature. If the lag is assumed to be 30 seconds, the indication lags 3° C.

METHOD OF DETERMINING LAG AND EXPERIMENTAL PROCEDURE

The following relation is given by Harper (see previous reference) as the basis for the method here used of determining lag:

$$\lambda=\frac{t}{\log_e\frac{T_o-U_o}{T-U_o}} \qquad (3)$$

in which T_o is the indication of the thermometer when the time, t, equals zero and T its indication at time t, while the thermometer is immersed in a bath at temperature U_o. This relation is subject to certain assumptions which are valid for the determinations here reported.

The temperature elements of the thermometers under tests were brought to a temperature $T_o=0°$ C. and then suddenly immersed in an air stream of a wind tunnel at room temperature U_o, which was approximately +25° C. Observations were made of the changing readings of the thermometer at known intervals of time. The temperature of the air in the wind tunnel, U_o was also carefully noted and was found to be constant during the short period of time required to obtain the wind tunnel observations, usually about one minute. Any inaccuracies in this connection would appear in a marked departure from a straight line of the points at the right end of such curves as are plotted in Figure 1.

The wind tunnel consisted of a cardboard tube 10 inches in diameter built around two electric fans, one placed at each end of the tunnel. An opening was cut in the middle of the tube and a French Pitot-Venturi nozzle of known calibration was inserted in order to measure the air speed. The pressures developed by the nozzle were observed on a water manometer. On 110 volts the fans gave an air speed of 10 m. p. h.; on 220 volts, an air speed of 17 m. p. h.

Thin sheet-metal containers, just large enough to hold the various thermometer bulbs, were used to keep the bulbs dry while packed in cracked ice.

[1] Published by permission of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

[2] Thermometric Lag, Bulletin, Bureau of Standards 8, p. 659-714, 1912 (S. 185).

The bulbs of all indicating instruments were placed in the wind tunnel so that the long axis of the instrument or element was at right angles to the long axis of the wind tunnel. The principal planes of the temperature elements of the thermographs were parallel to the axis of the wind tunnel during the tests.

RESULTS

The elapsed time in seconds plotted against the expression

$$\log_{10}\frac{T_o - U_o}{T - U_o}$$

for an air speed of 17 m. p. h. is shown in Figure 2 for each instrument. The slope of any line when multiplied by 0.434 in order to obtain logarithms to base e is the lag in seconds. A brief description of the instruments, including values determined for the lag, is given below.

A: A liquid-in-glass column-type instrument designed for use as a strut thermometer. The corrugated cylindrical bulb was unusually large (1.75 inches long by 0.43 inch in diameter) and contained a considerable mass of liquid. It was protected by a metal shield which was perforated so as to permit air flow around the bulb. Similar to instrument shown in Figure 10 of National Advisory Committee for Aeronautics Technical Report No. 126 on Altitude Instruments. Lag, 57 seconds.

B: A thermograph with a liquid-filled Bourdon tube for the temperature element. The tube (2.25 inches long, 0.62 inch wide, and 0.06 inch thick) had a considerable mass of metal as well as liquid. Lag, 33 seconds.

C: A strut thermometer. This instrument was similar to instrument *A* above, including also the protective covering of the bulb, except that the bulb was rather long, thin, and flat (3.25 inches long and 0.5 by 0.19 inch in cross section), and had somewhat less mass. Lag, 32 seconds.

D: An ordinary "chemical" mercury-in-glass thermometer. The bulb was rather small (0.5 inch long by 0.19 inch in diameter). Lag, 18 seconds.

E: An electric resistance thermometer. The temperature element, *T*, mounted on top of the wind tunnel, was a No. 36 silk-covered nickel wire wound upon a thin metallic tube (2.25 inches long by 0.62 inch in diameter). The resistance was 205 ohms at room temperature. Holes had been bored into the outside protecting tubing so as to reduce the lag. The temperature lag for this particular bulb was found to be 17 seconds (the average of six determinations) at an air speed of 17 m. p. h. and 22 seconds (average of two determinations) at an air speed of 10 m. p. h.

F: A thermograph with a bimetallic strip temperature element (2.5 inches long, 1 inch wide, and 0.023 inch thick). This instrument, as expected, had the lowest thermometric lag of all the instruments so far tested. Lag, 13 seconds.

Data given by Harper for a "chemical mercury thermometer" cover a range from 0 to about 24 miles per hour. Extension to flying speeds involves a very considerable extrapolation, but by plotting $1/\lambda$ against log speed, the curve can be approximately rectified, and extrapolation of this rectified curve indicates that at flying speeds the lags would be approximately half of those determined at the air speed of 17 m. p. h. The data for two speeds given for instrument *E* also indicate that at flying speeds the lag would be about half that determined at the lower speeds.

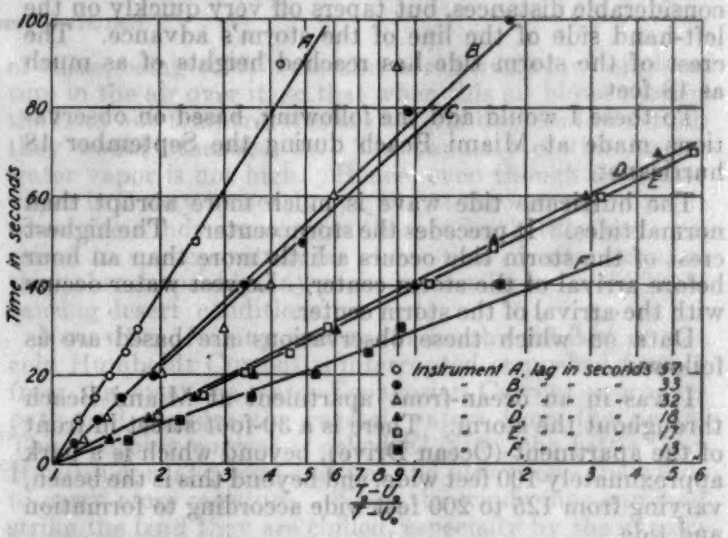


FIG. 1.—Curves obtained in determining the lag in an air stream of 17 m. p. h. Values of the lag are included.
A: Strut thermometer, liquid in glass, bulb inclosed.
B: Thermograph, Bourdon-tube element.
C: Strut thermometer, liquid in glass, bulb inclosed.
D: "Chemical" thermometer, mercury in glass.
E: Electric resistance thermometer.
F: Thermograph, bimetallic strip element.

SUMMARY

The thermometric lag of six aircraft temperature instruments ventilated by an air stream of 17 m. p. h. was determined with the following results:

A: Strut thermometer, liquid in glass, bulb inclosed, 57 seconds.

B: Thermograph, Bourdon-tube element, 33 seconds.

C: Strut thermometer, liquid in glass, bulb inclosed, 32 seconds.

D: "Chemical" thermometer, mercury in glass, 18 seconds.

E: Electric resistance thermometer, 17 seconds.

F: Thermograph, bimetallic strip element, 13 seconds.

In general, the liquid-filled types have lags which are excessive for aircraft use.

A LAYMAN'S NOTES ON THE HURRICANE TIDE AT MIAMI

By W. J. SCHUBERT
[Miami, Fla., March 8, 1927]

In the MONTHLY WEATHER REVIEW I read an article [1] several years ago on hurricane tides in which, as I recall it, the following facts were set forth:

The hurricane tide has no connection with moon or sun. It is driven up by the winds in the right-hand rear quadrant of the storm which are the most violent of all. It reaches its highest crest close to the right-hand side of the line of the storm's advance and extends outward for considerable distances, but tapers off very quickly on the left-hand side of the line of the storm's advance. The crest of the storm tide has reached heights of as much as 18 feet.

To these I would add the following, based on observations made at Miami Beach during the September 18 hurricane:

The hurricane tide wave is much more abrupt than normal tides. It precedes the storm center. The highest crest of the storm tide occurs a little more than an hour before arrival of the storm center. Lowest water occurs with the arrival of the storm center.

Data on which these observations are based are as follows:

I was in an ocean-front apartment at Miami Beach throughout the storm. There is a 30-foot street in front of the apartment (Ocean Drive), beyond which is a park approximately 100 feet wide, and beyond this is the beach, varying from 125 to 200 feet wide according to formation and tide.

At midnight I visited the beach. Wind was coming from almost due north, which made it parallel to or slightly off shore. There was little surf, the waves being less than 18 inches high. The wind had not reached gale proportions. The eastern sky was heavily overcast, but in the west it was clear and comparatively bright (the moon was nearly full) and stars clearly visible. The tide was normal.

At 2 o'clock a. m. I again visited the beach. The wind had increased rapidly meantime and had now reached destructive force, making it necessary to crawl, as walking was impossible. Trees were breaking and falling, visibility was practically nil (less than 20 feet), and the air was filled with sheets of horizontally driven salt spray. The roar of the storm was appalling. I found the water's edge showing normal tide and little surf.

After this time the wind reached such violence that it was impossible to again visit the beach until arrival of the storm's center.

The salt spray had filled the street level full and had also filled all low spots; but at 3:50 a. m. I noted a definite rise in the water over a sidewalk on the south side of the building, and by 4:30 a. m. salt water was 23 inches above the sidewalk. At 4:10 a. m. I heard a muffled thud, saw water spurt in around the front door, and, going to the side door, saw a breaker, perhaps 18 inches high, crested with broken water, roll past and disappear in the darkness inland. After this the breakers came regularly and continuously until 4:50 a. m. when they disappeared. Their greatest height was perhaps 24 inches about 4:30 a. m. I also found a big Gulf Stream jellyfish just outside the door on the sidewalk in the water at 4:25 a. m.

After 4:30 a. m. the water receded slowly at first, then faster, and at 5:05 water had disappeared excepting for puddles in the low spots.

During this time the wind continued with extreme and constantly increasing violence from very nearly north.

Daylight now began to filter through, and at 6:05 a. m. the wind suddenly fell to a light air and rapidly shifted to southeast by south. The air cleared and visibility increased to perhaps 3 miles.

I at once visited the beach. I found the water at least a foot below normal low water—the lowest I have ever seen it. A tremendous surf was now pounding in from the southeast. At 6:40 a. m. a dark squall drove swiftly in from the southeast, and in 10 minutes the wind had reached greater violence than before.

I presume the tremendous force of the wind, which was now diagonally on shore, again piled the water up ahead of it to some extent and that there was another rise in the tide on the beach. Violence of the wind, however, utterly precluded any attempt to confirm this, and the air was so filled with spray that the ocean was entirely invisible.

As nearly as I can determine, therefore, the storm tide rose between 9 and 10 feet in the two and one-half hours between 2 o'clock a. m. and 4:30 o'clock a. m. It fell between 10 and 11 feet in the hour and a quarter between 4:45 and 6 o'clock a. m. It reached its highest point an hour and twenty minutes before arrival of the storm center and its lowest point when the storm center arrived.

My position was evidently in the northern (or right-hand) edge of the storm center. The sky never entirely cleared and I did not see the sun, but both clear sky and sunshine occurred 4 miles farther south during passage of the center.

Proximity of the Bahama Banks, some 45 miles east of Miami Beach, probably prevented the winds from driving up such a high storm tide as occurred at Galveston. This fact, together with the fact that the wind was slightly off shore prior to arrival of the storm center, was probably the salvation of Miami Beach.

The figures and time mentioned here do not coincide exactly with observations made along the water-front in the bay; but it is my opinion that in the bay local conditions, such as the shape of the bay, the inability of tidal waters to get in and out quickly, and other factors, had some effect.

Other phenomena I noted were:

Hurricane winds, or at least the clouds, mist, and spray, that accompany these storms, must be rather shallow. For after the sun rose, even when the storm was at its height, there was almost sufficient light to throw shadows. At the same time the air was so filled with horizontally driven salt spray, mist, and rain that houses 300 feet distant were entirely invisible and those 200 feet away could be seen only faintly.

The barometer, which reached its extreme low of 27.61 about 6 o'clock a. m., rose so rapidly when the storm center arrived that movement of the hand was actually visible. In the first few minutes it rose above 29. Of course it again quickly fell to nearly its former low when

[1] Monthly Weather Review 48: 127–145.

the center passed. This change in atmospheric pressure was not noted nor mentioned by any of the occupants of the apartment. All, however, complained of the heat, especially during the earlier hours of the storm.

After the storm I found a live grouper, weighing perhaps 60 pounds, in a puddle three blocks back from the ocean. I also saw several fish, principally grouper, half buried in the sand that covered the Ocean Drive. I counted the following day above 300 dead fish on the beach in a distance of a quarter of a mile. Nearly all were bottom fish—groupers, snapper, sailor's choice, grunts, progies, sheepshead, toadfish, etc. Of the surface swimmers I saw perhaps a dozen mullet, but the halfbeaks (or ballyhoo), the needlefish, etc., were entirely absent.

The great majority of these fish had evidently washed ashore after the main storm had passed, as they lay down at the edge of the water where a small surf had left them. The heavy seas I saw breaking during the storm center had gone far higher.

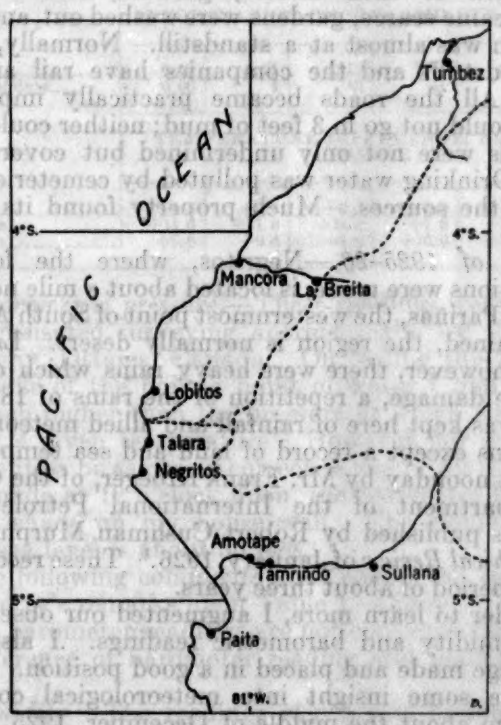
METEOROLOGICAL OBSERVATIONS AT NEGRITOS, PERU, DECEMBER, 1924, TO MAY, 1925

By E. WILLARD BERRY

[Dated Negritos, Peru, June 15, 1926]

The desert of northwestern Peru, better known locally as the Desert de Tumbez, is the center of the oil fields of Peru. In this northwestern region are located the fields of the International Petroleum Co. (Ltd.) of Canada, the Lobitas Co., and the Zorritos Co. Very little has been written of its climate, and of late years, its floods.

The Northwestern Desert of Peru is an area extending from Rio Tumbez on the north to Rio Chira on the south, in all about 140 miles long, and from the sea on the west to about the crest of the coastal mountain ranges on the east, roughly 50 miles wide. This desert under normal



conditions is one of the driest in the world. There is, during normal years no measurable rainfall. Along the coast a little mist collects on roofs and drips off, but this is all. Yet rains actually do occur here. The proximate reason for their occurrence seems to be the weakening or shifting of the Humboldt or Peruvian Current. The west coast of South America is washed by this cold current and by more or less upwelling of deep water along the coast due to the earth's rotation. The Humboldt Current runs northward at such a rate as to be appreciable in coastwise shipping. It flows along the coast as far north as the region of Cabo Blanco, where it is met by the warm Ecuadorian Current and turned westward to form the Pacific South Equatorial Current. The first of these, being cold, maintains a relatively low temperature in the air over it, so that when this air blows toward the land our temperatures are several degrees lower than they would otherwise be. The capacity of this air for water vapor is not high. Hence, even though the water vapor in it may be nearly or quite at the saturation point when the winds arrive over the hot land, they are soon raised to a temperature far above that of saturation, so they absorb quickly any moisture available on the land, causing desert conditions.

Now when, for any reason, the northward flow of this cold Humboldt Current is interrupted or pushed further from the coast the warm Ecuadorian Current usurps its path and invades the coastal waters from the north. This usurping current is called El Niño, the Little One. It raises our land temperatures and also allows the winds to carry more moisture. When the winds thus enriched strike the land they are chilled, especially by the sudden radiation from the land after sunset, and the saturation point being lowered, rain occurs. This is what appears to have happened in 1925 and 1926.[1] There are references to other floods in 1856 and later in 1891.

Speed of El Niño.—On March 6, 1926, when the sea temperature at 12 o'clock was 90°, I noticed at about noon several large masses of drift in the sea. Such masses are uncommon, hence very noticeable. The night before had been rainy and the bridge at Quebrado Parinias, which is at least 15 miles to the north, had washed away. Of the 15 miles, 6 are in the quebrado and the other 8 are in open sea. The bridge went sometime during the night of March 5 and the drift beached about 1 p. m. on March 6. It had taken not more than 15 hours to make the 15 miles. A mass of drift that I timed made 4,000 feet in 50 minutes, or about 4,800 feet an hour. I believe this estimate to be nearly correct, as the material would travel faster in the quebrada than in the open sea. This is only one example of the way the currents went south this year. I have also picked up mangrove seeds on the beach. As far as I can ascertain there are none growing to the south and the nearest to

[1] It seems not likely that chilling of the warm, wet wind by contact with a radiation-cooled land surface could be more than a very minor cause of the precipitation described. The only air to be largely affected by such cooling is the thin surface stratum through which the very slow process of conduction could work, the stratum being only a very few feet thick even under the most favorable conditions of great calm. Turbulent mixing of this thin skin of cooled air with air not so cooled, above, would promptly reduce the effectiveness of the cooled air as a rainmaker. One must look for action on a far grander scale than this as the cause of the downpour described by the author.

Only violent convection can cause violent rain. There must have been present in the situation discussed at least two causes of violent convection: (1) The forced rising of warm and heavily moisture-laden air against the highland barrier; (2) the recognized tendency at sea, especially in warm latitudes, to the occurrence of nocturnal showers even in the absence of an obstructing land. These showers are the result of strong convection induced by nocturnal cooling aloft so greatly in excess of the restrained cooling at the sea surface that the resulting superadiatic lapse rate causes convectional overturning. Now, nocturnal showers over this coastal land were one of the characteristics of the rains described later in the present paper. The moisture for them may well have been brought inland from the sea, either as showers already in process (in which case they would be strongly augmented by forced rising against the highland) or as a vast supply not yet released by convection over the sea, but only awaiting the very effective trigger action of the forced rising to let loose the fierce cloudbursts described.—*B. M. V.*

the north are at Puerto Pizarro at the mouth of the Tumbez River.

I have found a few drift seeds similar to those called snuff or box beans and valued as charms by the women of the Shetland Islands, north of England. How far these may have come I have no means of telling, as I do not know the extent of their habitat, but I am sure they came from the north and not the south.

The coastal region.—This coast when seen from a steamer is sand, backed by steep hills cut by deep narrow valleys, all ending in a series of flat plains or tablazos, which are really Pleistocene wave-cut terraces. The entire landscape normally is a dull, lifeless, sandy brown. Here and there in the bottoms of the quebradas are green bits, where grow a few algarroba trees (*Prosopis*) and some grass and vines. The tablazos are barren, covered with sun-split pebbles. Few if any of the valleys or quebradas reach the sea. Sand dunes close them off and any water they have is lost in the sand.

Along the coast the cliffs rise suddenly from sand-covered flats. In the southern part of the region these flats form great salt fields or salinas, absolutely barren and usually show white with salt left by the evaporated sea water. However, from Point Pariñas northward there is an ever-increasing cliff dissected by narrow, deep valleys or quebradas. On top of the tablazos these valleys can not be seen until one has almost reached their edge. Then they remind one of the Grand Canyon of the Colorado on a small scale, or some of the Bad Lands of Montana. The land plant life near the shore on these tablazos is nil under normal conditions. Further inland there are a few stunted trees, and in the northern part of the desert one finds cacti.

On the eastern edge of the desert near the mountains more vegetation is found. Orchids, cacti, and air plants, which look like misplaced pineapple tops, flourish, and there are several varieties of small trees growing in the foothills. One, a sort of poisonous sumac, is quite common in the northern part of the desert.

When the rains come the quebrados flow water. There are often floods where sand dunes left by the winds dam up the water until it gains sufficient force and the sand is broken through. Where this occurs everything is washed away—roads, bridges, wells, and houses are either completely demolished or badly damaged. The waters subside, leaving a muddy waste which after a few weeks of sunshine and growth blossoms into a new beauty. Everywhere plants spring up, not new or uncommon species, but millions more of the same kinds whose seeds have been accumulating since the last rains. Even the desolate and wind-swept tablazo turns green. Grasses grow 2 and 3 feet high. A sort of wild alfalfa, reeds, and many legumes predominate. The tablazo, once a barren plain, is clothed in verdure. Cattle are imported and wax fat on this luscious new diet. The burros, in the past hardly more than skin and bone, fatten until they almost overreach the limits of their crude crossed-stick pack saddles. Even the goats look as if their skins were too small. In the quebrado bottoms after the flood large crops are planted; cotton and table vegetables do well; areas near the streams are irrigated. On old dead trees, wild gourds and a wild prickly cucumber grow rank.

But let six months pass. The grasses are brown, dry, and sere. The cattle are killed and eaten, or driven to better pastures in the mountains. The burros are again thin and gaunt. The goats are climbing at the trees for bark. The irrigated crops have been harvested. The wild vines are dry and rustle as the breeze plays through their dead stems. Pools linger in the bottoms until the water, becoming more and more brackish, is finally so salt that a crust forms over it, and it, too, soon dries up.

The few people living here who are not under the control of the oil companies live either in small houses built of odd-shaped, gnarled bits of wood packed between uprights or in reinforced mud huts. Needless to say, they are not weatherproof. The roofs are built for shade rather than to turn water. Near the watercourses cane is grown and used for building.

These native houses were glutted by the rains. At Sullana, on the Chira River, the native market, built of adobe, had one side dissolved out and is still being repaired. In Amotape, a small town near the river, there were whole streets where the adobe houses had dissolved and the roofs caved in, presenting a spectacle of sad desolation. The small settlements in the river bottoms were literally destroyed. Pools forming in every slight depression became the breeding place of hordes of mosquitoes, and malaria became common. Natives died rapidly, weakened by exposure and discouraged by the destruction of their houses, gardens, and livestock. Food became scarce, gardens were washed out, and transportation was almost at a standstill. Normally, burros pack foodstuffs and the companies have rail and auto roads. All the roads became practically impassable. Burros could not go in 3 feet of mud; neither could autos. Railroads were not only undermined but covered with mud. Drinking water was polluted by cemeteries washing into the sources. Much property found its way to the sea.

Rains of 1925–26.—Negritos, where the following observations were made, is located about a mile northeast of Point Pariñas, the westernmost point of South America. As explained, the region is normally desert. Last year (1925), however, there were heavy rains which did considerable damage, a repetition of the rains of 1891. No record was kept here of rainfall and allied meteorological conditions except a record of land and sea temperatures taken at noonday by Mr. Frank Kroeger, of the Geological Department of the International Petroleum Co. This was published by Robert Cushman Murphy in the *Geographical Review* of January, 1926.[1] These records now cover a period of about three years.

In order to learn more, I augmented our observations with humidity and barometric readings. I also had a rain gauge made and placed in a good position. Table 1 will give some insight into meteorological conditions here from about the middle of December, 1925, to May 31, 1926.[2]

[1] See also by the same author: "Recent oceanic phenomena along the coast of South America." MO. WEA. REV. 53: 116–17.—ED.

[2] For convenience the daily readings have been combined in monthly averages, and these averages appear in Table 1. At the bottom of that table the differences between air and ocean temperatures are given. The monthly averages are based on from 24 to 27 observations per month. The greatest period of missing observations did not exceed four days.—ED.

TABLE 1.—*Summary of meteorological observations made at Negritos, Peru, December 18, 1925–May 31, 1926*

[Pressure and temperature at noon; humidity at 11 a. m.; precipitation measured in a home-made gage and given in inches and hundredths. E. Willard Berry, observer. As a rule observations were made on 20 to 25 days in each month]

	December	January	February	March	April	May
PRESSURE (INCHES AND HUNDREDTHS)						
Mean	29.48	29.49	29.47	29.48	29.48	29.50
Maximum	29.55	29.55	29.53	29.55	29.56	29.57
Minimum	29.40	29.35	29.40	29.38	29.38	29.45
AIR TEMPERATURE						
Mean	78.7	82.9	87.1	87.8	89.7	84.4
Maximum	80.0	91.0	92.0	92.0	96.0	91.0
Minimum	81.0	83.0	74.0	84.0	86.0	79.0
WATER TEMPERATURE (SURFACE OF OCEAN)						
Mean	74.2	75.5	78.0	81.8	75.0	69.3
Maximum	76.0	80.0	81.0	85.0	83.0	71.0
Minimum	72.0	73.5	75.0	74.0	72.0	67.0
RELATIVE HUMIDITY (PER CENT)						
Mean	68	60	71	73	59	61
Maximum	85	83	96	96	85	82
Minimum	57	38	60	55	49	56
PRECIPITATION (INCHES AND HUNDREDTHS)						
Total	0.00	0.21	2.12	7.80	0.35	0.01
Number of days	0.00	4	10	14	4	1
TEMPERATURE DIFFERENCE, AIR MINUS WATER						
Mean	+4.5	+7.4	+9.1	+6.0	+14.7	+15.1
Maximum	+14.0	+11.0	+11.0	+7.0	+13.0	+20.0
Minimum	+9.0	+9.5	−1.0	+10.0	+14.0	+12.0

1. *Barometric pressure.*—These readings were taken on a compensated surveying aneroid made by the Topley Company, Ottawa, Canada. On testing this barometer by means of the boiling point of water I find that it is 0.38 inch higher than the pressure at which water would boil at a given temperature. However, for most uses I believe it to be as nearly correct as any. All the readings were made at 12 o'clock noon, the barometer being fixed in the shade on my house wall. The elevation above mean sea level is about 50 feet.

[The following comments are a condensed summary of Mr. Berry's remarks upon Table 1.—*Editor.*]

The barometer readings are not corrected for elevation or difference of barometer reading and boiling point of water.

Humidity.—The readings were made beside the Geological Offices of the International Petroleum Co. at Negritos. I took them on wet and dry bulb thermometers which were in both draft and shade. They were made at 11 a. m., and the daily values were taken from Fox-Burough tables.

Air temperature.—Observations of air temperature were made at 12 o'clock noon, beside the wet bulb thermometer at the geological office. Mr. Kroeger began recording these readings about 3 years ago. I am indebted to him for both the air and water temperatures. The latter were taken off the end of the small steel mole extending about 50 feet beyond the mean tide mark. A heavy crock is heaved over and allowed to chill and fill with water. It is then pulled up and the temperature of the water read on a chemical thermometer.

Water temperatures.—The table shows a rise from December through March and a decided drop in April and a still lower temperature in May. However, during April the relation of land and sea temperature is not at all like their relation during the first two months of the year. For some reason the land temperatures were much higher than the sea temperatures; that is, they did not decline together.

Rain.—Last year during the "floods," so called hereabouts, no good record of rainfall was taken. Mr. Blogett, a driller, living at La Brea, about 12 miles to the east, told me that an empty metal barrel had 37 inches of water in it after the rains. How much evaporated no one can say.

I am told by several people that a locomotive, mired 5 or 6 miles south of here, had a common galvanized pail about 10 inches deep, 9 inches in diameter at the bottom, and 12 inches in diameter at the top, placed upright in the stack. The next day the pail was found overflowing with rain water.

This year the rains were not so heavy, judging from the damage done to roads, houses, and the like. Starting on the night of January 18 and raining now and then until the night of May 24 a total of 10.446 inches of rain fell. The greater part of this fell in March.

March had the highest humidity, the highest sea temperature, and the most rain.

The following observations extend over this period of rains.

The rains seem to have been of a very local character. On February 6 I drove to Catalinas, in Quebrado Mancora, about 35 miles to the north. Leaving there about 12:30 p. m. I started back to Negritos and had gone only a little way, about a mile, when I ran into a shower. We were apparently running with the storm, but after several miles we changed our direction. The road ran over steep hills and they were wet and slippery, so our progress was necessarily slow. In spite of this in 5 miles we were ahead of the shower and in open sunlight.

Heavy showers were often to be seen further inland in the Amotape Mountains. These showers seldom come far from the foothills. During Easter (April 1–4) I was camping in the foothills of the mountains. On April 2 at 7 o'clock it was a sapphire night. In about 10 minutes a fog was about us and shortly afterwards it began to rain extremely hard and continued to do so for an hour. To the best of my knowledge it rained over an inch during this shower. A straight-sided cook pot was left in the open contained an inch of water the next morning, so, allowing for evaporation, which is rapid, fully an inch must have fallen. I inquired next day at a place a mile distant and was told no rain had fallen there.

On the night following I came out to the coast and camped on Point Arena about 4 miles north of Negritos. That night also started out clear, so clear in fact that I did not put up a tent. However, at 12:30 a. m. we were awakened by a downpour which lasted about 25 minutes, the rest of the night interrupted by showers of a second or two. On returning to Negritos the next afternoon (April 4) I was told there was one very slight shower during the night. For the days of April 1, 2, and 3 my rain gage registered a total of only 0.15 inch of rain. This indicates how local the rainfall was.

One night in Negritos it rained about a half an inch in about five minutes. The same night a culverted railroad embankment about 3 miles inland was completely washed out and much other damage was done.

Some of the rains were accompanied by lightning, but so far as I know no damage was done by that agency.

Quite often before rains I noticed clouds over the sea. These clouds were not the fairly common cloud banks which one can observe off many coasts. They were low lying, though not touching the horizon—flat bottomed and almost stationary, very like the common flat-bottomed clouds of the trade-wind areas.

Prevailing winds here are from the south. A north wind was frequently the forerunner of rain, although this was not always the case.

When I arrived here last November small briny pools were still to be found inland. This year there are some, but I very much doubt whether they will be left five months from now.

Parinas, a dry stream under normal conditions, has been flowing now since the rains in 1925. Mr. Oscar Haught tells me, however, that it does not seem to be flowing as much water as it did this time last year.

Last year the country hereabouts blossomed forth with large numbers of plants. In December, 1925, the desert was bare and brown, but after the rains started grass and many legumes came up and grew both fast and rank. One of the legumes has a yellow flower and a long seed pod with almost cylindrical seeds. It often grows so high that you can not see over it from the seat of a Ford car.

These same rains also made pools on the Tablazo which attracted many wild ducks, affording our hunters much sport. The pools also bred mosquitoes, which are absent here under normal circumstances.

Discussion.—The almost complete absence of meteorological observations from Peru, save only from Lima, makes it difficult to visualize the meteorological changes that were associated with the extraordinary rains of February–April, 1925. The southward extension of the El Niño current in that year, seems to have taken place as early as the middle of January or a few days later. In 1926 the water temperatures as measured at the end of the steel pier at Negritos, Peru, first reached a height of 80° on January 27; the temperature then sank slightly below that figure and remained below about two weeks, again reaching 80° on February 11 and continuing close to that figure until the end of the month.

March opened with ocean water temperature at 82° and fell to 79° on but a single day until the 20th. A water temperature on the 21st is missing but on the 22d a temperature of 74° was registered—a drop of 9° from the 20th; on the 23d it had returned to 79° and continued about that figure until the end of the month.

On April 9 it registered 83° for a single day and then sank to 78° on the 10th.

These figures seem to indicate that the retreat of the warmer water proceeds irregularly and that fragmentary incursions of warm water may be experienced some days after the cessation of the warm current.

The meteorological statistics with the exception of the land and sea temperatures throw no light upon the cause of the extraordinary rains over the normally desert areas of northwestern coastal Peru.

The outstanding features of these statistics are the high ocean temperatures of March and the heavy rains of that month and the cessation of the rains so soon as the ocean temperature fell to approximately normal values in April and May. The high ocean temperature would increase the air temperature locally both by conduction and convection, and the contact of these local masses of warm air with the adjacent Peruvian highlands would doubtless cause the rains as observed. The drift of overlying ocean air landward must occur with some regularity, especially during the night hours, and there must have been a countercurrent seaward during the daytime hours; wherefore it is inferred that the disturbed air conditions were local rather than general and due to the unusual extension of El Niño current to the southward.—*A. J. H.*

In connection with Mr. Berry's paper and the above discussion, the following reprint from the Bulletin of the National Research Council, Volume II, part 2, No. 56, November, 1926, is of interest:

INVESTIGATIONS OF THE AMERICAN MUSEUM OF NATURAL HISTORY IN THE HUMBOLDT CURRENT REGION

From December, 1924, until March, 1925, the writer, accompanied by Mr. Van Campen Heilner, conducted marine zoological investigations for the American Museum on the coasts of Peru and Ecuador. A report on the oceanographic phases has since been published (Oceanic and Climatic Phenomena along the West Coast of South American during 1925, Geographical Review, vol. 16, pp. 26–54, 1926). This paper is supplemented, moreover, by another of more popular nature (Equatorial Vignettes, Natural History, vol. 25, pp. 431–449, 1925).

The problem on the arid west coast of South America is highly complex. In their incipience, the factors which produce the periodical changes are doubtless purely meteorological, while the end stages, because of the peculiar topography of the western watershed of the Andes, involve profound geographic effects. The intervening phenomena in the grand sequence are, however, distinctly oceanographic. The notably stable physical characteristics of the littoral ocean of this coast, and the consequently undue disturbances which occur during the rare cycles in which such characteristics are altered, are alike unequaled elsewhere. In no other part of the world does a simple reversal in direction of the coastwise oceanic circulation lead to such spectacular climatic, biological, and economic results.

The writer worked entirely from launches and other small craft, and his equipment was limited to surface apparatus. His data, therefore, do not lead to an understanding of the extent in breadth or depth of the warm countercurrent which for many weeks during the winter and spring of 1925 replaced the Humboldt Current, at least at the surface, bringing about the cessation of cool upwelling and preparing the way for perhaps unprecedented rainfall along the desert coast. Even as regards simple surface temperatures, all the tables thus far obtained from the pertinent section of the Pacific, record conditions only along coastwise tracks, within a few miles of shore. The data urgently needed are routine observations made at right angles to the trend of the coast, and extending for a thousand miles or more along any parallel between the equator and latitude 30° S. Such data, especially if accompanied by subsurface records, might reveal whether the counter-current known as El Niño was in the nature of a restricted coastal tongue or whether the phenomenon represented a surface movement of colossal extent in the wake of retreating high-pressure areas. A search for figures which may throw light upon this question is now being made, with the aid of Doctor Littlehales, of the U. S. Hydrographic

Office, and of several cooperating friends in South America.

The precipitation on the coast of Peru during 1925 has been recorded as certainly the heaviest since 1891; but there are reasons for believing that the conditions have not been paralleled during the course of at least six centuries. Prior to March, 1925, for example, the mud walls of the prehistoric fortress of Chan Chan, near Trujillo, still bore clearly the ancient reliefs and hieroglyphics of their builders, but the rainfall of a few subsequent weeks entirely obliterated them. The destruction of life in the sea, through a process which the writer has elsewhere described, was also unprecedented within human memory. Under date of January 30, 1926, Mr. Francisco Ballén, director of the Peruvian National Guano Administration, writes that probably two-thirds of the sea-bird population of the Peruvian coast, as existing in December, 1924, perished during the following months of unfavorable oceanic conditions.

Fortunately the serious economic effects of the countercurrent and its sequelae have simplified the study of meteorological and oceanographic problems by encouraging the recording of precise data. Through the interest of the American ambassador in Lima, of Maj. Otto Holstein, of Trujillo, and of other friends and correspondents in the service of numerous Peruvian industrial organizations, tabulated records of the climatic and oceanic régime are now being received regularly. These are deposited in the files of the American Geographical Society of New York, and their subsequent interpretation can not fail to go far toward illuminating our faint understanding of one of the most remarkable geographic phenomena of our time.—*Robert C. Murphy.*

NOTES AND ABSTRACTS

E. W. BLISS ON BRITISH WINTERS IN RELATION TO WORLD WEATHER

The author in continuance of his previous work on correlation of world weather correlates the mean winter temperatures of Greenwich with elements of the weather in various parts of the world.

The correlation coefficients with pressure, temperature, and rainfall in various quarters of the earth are shown in the exhibit below.

Number of coefficients 0.4 or greater

	Preceding quarter	Contemporary quarter	Succeeding quarters
Pressure	1	4	0
Temperature	8	6	3
Rainfall, etc.	1	1	1

Ten of these coefficients are with the two preceding quarters, eleven with the one contemporary quarter and four with the two subsequent quarters. The large coefficients are therefore mainly with previous and contemporary quarters. The author concludes as follows:

> Out of 310 correlation coefficients with Greenwich temperature of December to February as representing winter in Northwest Europe the largest appear to indicate the following relationships—
> (1) With pressure of the previous summer at Cairo.
> (2) With temperature of the previous June to August at Madras, Samoa, Batavia, and Perth.
> (3) With the previous Nile flood, the relationship here being inverse.
> The results indicate that conditions in the Southern Hemisphere play a part comparable with that of the North Atlantic oscillation in controlling subsequent winter weather in the British Isles.—*A. J. H.*

AEROLOGICAL WORK IN JAPAN[1]

This is the first published report of the Japanese Aerological Observatory at Tateno, where there is maintained a most complete meteorological equipment, including facilities for making aerological observations by means of pilot balloons, kites, sounding balloons, and captive balloons. This report contains data procured by double-theodolite pilot balloon observations only. The records cover two years (March, 1923–February, 1925) and total 1,030 observations. The balloons used weighed from 10 to 120 grams and the rates of ascent varied between 100 and 350 meters per minute.

There are included in the report a very complete history and description of the station, equipment, etc. Tables showing the wind velocity and direction at the various altitudes for successive minutes are given for each pilot balloon observation. Graphs are included, showing the:

Mean wind velocity (0–10 km.) for each season and for the year.

Mean annual wind velocity (0–2 km.) for 6 a. m., 10 a. m., and 2 p. m.

Mean wind direction (0–10 km.) for each season.

Mean wind direction (0–2 km.) for 6 a. m., 10 a. m., and 2 p. m. for each season.

Frequency of wind directions (0–10 km.) for each season.

Frequency of wind directions (0–2 km.) for 6 a. m., 10 a. m., and 2 p. m. for each season.

The report closes with a discussion of the agreement between the observed ascensional rates of pilot balloons and those determined by formula. A change in the formula was made in order to obtain a closer agreement with the average observed rates. Closer agreement was found to obtain between the observed rates and those computed from the formula used by the U. S. Weather Bureau than those indicated by the Dines's formula.

Among the conclusions cited are the following:

1. The observed rates were found to be generally greater than those computed from formula. (U. S. Signal Corps and Dines).

2. For the rate of 100 m/m the values almost coincide but the actual rate becomes 20% greater for rates of 200 m/m.

3. The following new formula was devised to obtain closer agreement with the observed data.

$$V = 74.6 \left\{ \frac{A}{(A+B)^{2/3}} \right\}^{\frac{1}{1.53}}$$

This fits closely for the stratum 1 to 3 km. but to reduce the values computed from the above formula to the mean observed values from 1 to 10 km. they must be multiplied by the factor $\frac{1000}{1071} = 0.934$.

4. The rate of ascent is greatest at 2 p. m. and least at 6 a. m. It is greater in winter than in summer.

5. The rate is greatest near the ground and decreases more and more upward but at 8 km. it increases again.

[1] Abstract of "Roporto de la Aerologia Observatorio de Tateno. Nol. By W. Oishi. (The report was translated by Mr. W. W. Reed from the original Esperanto.)

6. The increase near the ground is due to convection, turbulence, and somewhat to topographical influence.

It is extremely gratifying to know that such an excellently equipped station is being maintained, and future reports on the results of the various other branches of the work will be awaited with the greatest interest.—*L. T. S.*

THE ROYAL METEOROLOGICAL SOCIETY'S "RAINFALL ATLAS OF THE BRITISH ISLES"

The extent to which amateurs with an interest in the weather can supplement, or, indeed, make possible, a scientific work of great importance, is illustrated by this atlas. The British Rainfall Organization is composed of such amateurs. In the course of its long history it has enlisted the cooperation of some 10,000 voluntary observers. Its records placed at the disposal of the committee of the Royal Meteorological Society directing the preparation of the atlas the accumulated data from some 3,000 stations. This is an average of about one station to every 40 square miles, in an area three quarters the size of California.

The maps are beautifully printed in colors, and are as follows:

1. A generalized topographic map showing principal towns, the county boundaries, and chief rivers.
2. Average annual rainfall (35-year period, 1881–1915).
3. Rainfall of the wettest year (1872).
4. Rainfall of the driest year (1887).
5. Annual rainfall as percentage of the average of 1881–1915, for each year from 1868 to 1923, inclusive.
6. Twelve monthly rainfall maps.

Dr. Hugh Robert Mill contributes a very full introduction, describing the history of the British Rainfall Organization, briefly summarizing the facts shown by the maps of rainfall distribution, and presenting several tables.

Of the tables, that showing "Areas of the different rainfall zones over the British Isles" is of particular interest, the zones being the areas between limiting isohyets. In variation of rainfall from region to region, the British Isles rival our west coast States. Fifty-three square miles, mostly along the northern shore of the Thames estuary, have annually less than 20 inches, while 22 square miles of mountain country in northern Wales, northern England, and western Scotland average over 150 inches annually. Slightly more than 1,000 square miles have over 100 inches, and roughly one-fourth of the total area of the British Isles have 30 inches or less.

A table of percentage variations of annual rainfall, 1868–1923, brings out the fact that in 73 per cent of the years the generalized average rainfall for the British Isles has departed only 10 per cent or less from the normal, and in 87 per cent the departure has been 15 per cent or less.

To discuss at length the information embodied in this splendid work is quite beyond the scope of the present notice. The atlas is surely a fitting monument to the labors of Symons who organized and for many years directed the British Rainfall Organization, and to the zeal with which his successors, Wallis, Mill, and Salter have carried the work forward.—*B. M. V.*

THE RAINFALL OF FLORIDA

By GRAGG RICHARDS

[Author's abstract of a dissertation submitted to the Graduate Board of Clark University, Worcester, Mass., in partial fulfillment of the requirements for the degree of doctor of philosophy. The full text, with charts, may be consulted in the library of Clark University]

In presenting graphically the rainfall of Florida the standard methods, such as those used by Kincer for the United States, have been used. The data available for the 30-year period 1895–1924 are from 88 stations within the State, with records of 5 years or over, those covering less than the entire 30 years being adjusted to that basis.

While the range of mean annual rainfall for 30-year stations is from 57.88 inches at Pensacola to 37.19 inches at Key West, adjusted stations indicate values as extreme as 70.2 inches at Molino (16 years) and 32.1 inches at Sand Key (12 years). Except for the interior of the peninsula and the region of the keys, the mean annual rainfall is over 50 inches.

The mean of Florida as a unit, weighted by area from the chart of mean annual rainfall, is 53 inches, with 89.5% of its area receiving between 45 and 60 inches.

During the 30-year period all parts of the State, except the keys, have received over 60 inches in some years, while over 90 inches has been recorded at stations in west Florida and on the southeastern and western coasts of the peninsula. Minimum records also tend to be less on the coast than in the interior, varying, in general, from 30 to 40 inches.

For all of Florida more than half of the annual rainfall is in the half year April–September, varying from a nearly equal division in west Florida to over 70% in the southwestern part of the peninsula.

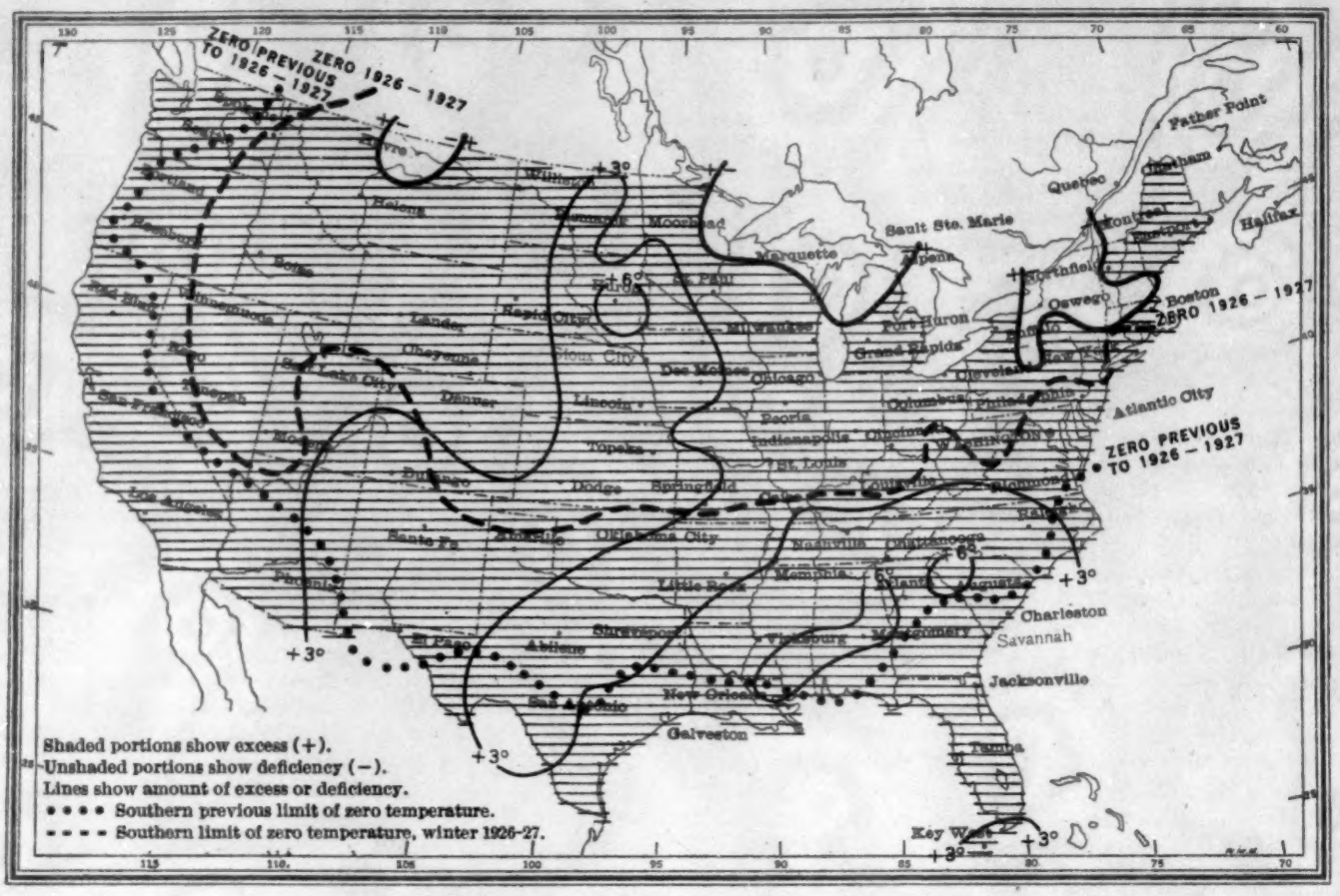
For the State as a whole, 19% of the mean annual rainfall occurs in spring, 40% in summer, 24% in autumn, and 17% in winter, but the actual distribution varies greatly with location. The southwestern coast of the peninsula receives nearly half of its precipitation in summer, while the southeast coast has heavier rainfall in autumn than summer, with over 35% of the annual amount. Extreme seasonal values vary from 48.33 inches, for New Smyrna, in an autumn (1924), to 0.17 inch, for a winter season (1906–1907), at Orlando.

All stations in Florida have a mean rainfall of not less than 6 inches in some months, the maximum varying from July in west Florida to October at points on the east coast. November is generally the month with least mean rainfall. All stations record less than 3.5 inches, as a mean, for some months, many between 1.5 and 2 inches.

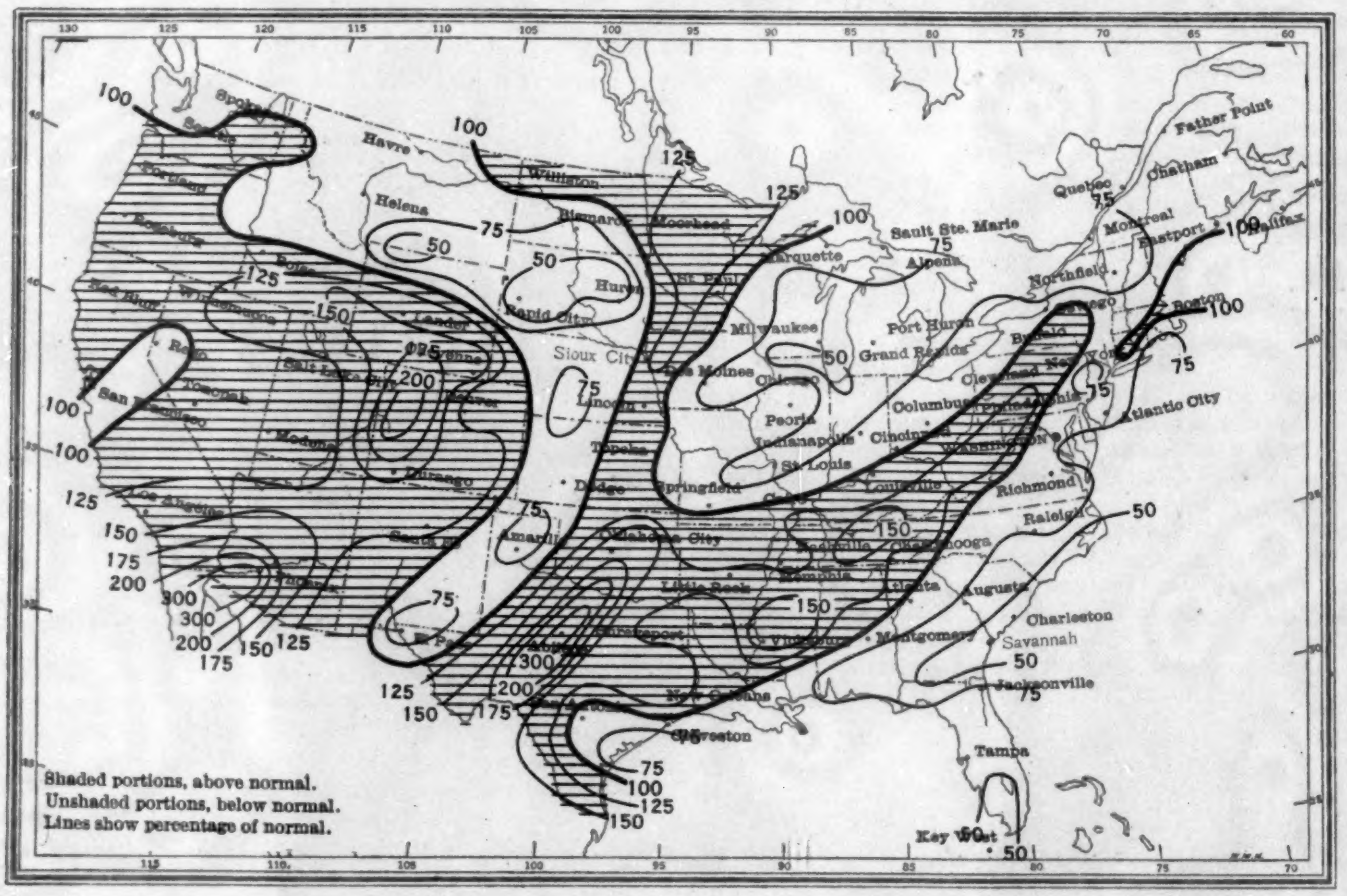
New Smyrna has recorded the highest absolute maximum monthly rainfall with 39.08 inches, while Pensacola has a high record of but 18.58 inches, and Key West of but 16.99 inches. Practically all of Florida has experienced a rainless month at some time during the period, though the lowest record for Brooksville is 0.10 inch.

Mean monthly rainfall data have been used for showing rainfall types. For this purpose, Ward, showing actual means, rather than Kincer, with monthly proportions of annual rainfall, has been followed, thus giving an idea of actual amounts, as well as proportions, in a single graph.

J. B. K. **I.—Departure of Mean Temperature from the Normal for the Winter (December-February) of 1926-27**


ZERO PREVIOUS TO 1926 – 1927
ZERO 1926 – 1927
ZERO 1926 – 1927
ZERO PREVIOUS TO 1926 – 1927
+3°
+6°
+3°
+3°
+3°
Shaded portions show excess (+).
Unshaded portions show deficiency (−).
Lines show amount of excess or deficiency.
• • • • Southern previous limit of zero temperature.
- - - - Southern limit of zero temperature, winter 1926-27.

J. B. K. **II.—Percentage of Normal Precipitation for the Winter (December-February) of 1926-27**



The type for the entire State shows a July maximum and a November minimum, with a secondary minimum for March–April. For the east coast there is a distinct type, with a principal maximum in September or October and a secondary maximum in June or July. Back from this coast the early summer maximum exceeds the later one, which disappears entirely farther inland.

In classifying the distribution of rainfall by causes, the daily weather maps for the 15-year period, 1910–1924, were studied and any precipitation for each of the six stations, Pensacola, Tallahassee, Jacksonville, Eustis, Tampa, and Miami, was segregated under one of the four headings: (1) Local convection, (2) cyclonic (extratropical) storms, (3) tropical disturbances, and (4) hurricanes. These data were tabulated for each station, showing both actual values of mean monthly and seasonal precipitation and their percentage of mean annual rainfall. An unweighted arithmetic mean for the six stations was used to give some idea of distribution by causes for the State as a whole.

The proportions found were: Local convection about 33%, cyclonic storms 40%, tropical disturbances 20%, and hurricanes 6%. Cyclonic storms account for over half of the mean rainfall in west Florida, but decrease in importance to the east and south, so that at Miami they account for but 25%, with corresponding increases from the other causes.

Half the spring rainfall in southern Florida is due to cyclonic storms, while over 75% is thus rated in west Florida. In summer local convection causes about 60% of the rainfall throughout the State. Tropical disturbances, including hurricanes, bring half the autumn rainfall for the State as a whole but are more important on the east coast. Winter precipitation is over 80% cyclonic, except for Miami, where the value is 60%. From the monthly data, the period November–May may be considered that of cyclonic storms, June–August of local convection, and September–October of tropical disturbances.

Marked variations above mean values, whether annual or seasonal, may generally be traced to a few tropical disturbances, more particularly those of hurricane intensity. Light rainfall, on the other hand, is explained by lack of such tropical disturbances in the warm season or by freedom from cyclonic storms in the remainder of the year.

ANOTHER MILD WINTER—1926–27 [1]

By J. B. KINCER

The United States has experienced, in recent years, a remarkable series of mild winters. The winter of 1917–18 was severe practically everywhere east of the Rocky Mountains, but following this, year after year, the winters have been moderate to unusually mild, as a rule, and that of 1926–27, just closed, was one of the mildest of the long series. The only exception to continuous winter mildness since 1917–18 was the winter of 1919–20, which was cold in Central and Northern States east of the Mississippi River, but otherwise mostly mild. The outstanding cases of widespread mildness for the series were the winters of 1920–21, 1923–24, and 1926–27, in each of which practically every State in the Union had a warmer than normal winter.

[1] Reprinted from Weekly Weather and Crop Bulletin, Mar. 15, 1927.

Chart I shows the departure of mean temperature from normal for the winter of 1926–27. It indicates that local areas in the Northeast and the upper Lake region, as well as a small district in the far Northwest, were slightly cooler than normal, but at all stations in these, except one, the temperature averaged only 1° subnormal. In all other sections of the country the winter was warmer than normal, and in large areas the plus departures ranged from 3° to as much as 6°. It was especially warm in the South, and as a result vegetation at the end of the winter season was much further advanced than usual.

The broken lines on Chart I afford a comparison between the southern limit of zero temperatures reported from first-order Weather Bureau stations during the past winter with previous records. While temperatures as low as zero have occurred in comparatively recent years as far south as the east Gulf coast, during the winter of 1926–27 subzero readings were confined to practically the northern half of the country, the zero line not extending farther south than Pennsylvania, Kentucky, and Missouri. In addition, the lowest temperatures for the winter in Northern States were generally well above the previous low record, being in most cases from 10° to 25° higher. There were no previous low records broken, but the maxima equaled or exceeded the previous high record at many stations, especially in the southern half of the country. In general, the winter should be classed as moderate in about half the country, probably moderately severe locally, and mild in the other half.

Chart II shows the percentage of normal precipitation for the three winter months. In most sections west of the Rocky Mountains the period was wetter than usual, particularly in the extreme Southwest and on the western slope of the central Rocky Mountain area where some stations reported more than twice the normal amount for the season. It was also above normal in most of the Southwest and over a belt extending from the lower Missouri Valley northeastward to southern New York, while a rather restricted area in the North Central States had more than the usual amount. In the Northwest, over most of the Great Plains, and generally from the Ohio River and extreme lower Missouri Valley northward there was less than normal, with some stations reporting only about half the usual amount. Precipitation was also deficient in the immediate Gulf section and generally in the Southeast and the Atlantic Coast States.

There was more than the normal amount of snowfall for the winter in many of the high elevations of the Western States and also along the northern border of the country from the western Lake region westward, while the amounts were above normal in most places in the northern Ohio Valley area, from the central Lake region eastward, and in Atlantic coast districts from Pennsylvania northward. In addition, local areas in Virginia and North Carolina and in northern Texas and Oklahoma had somewhat more than the usual amount. Elsewhere quite generally east of the Rocky Mountains there was less than normal snowfall, the deficiencies being especially large in the Missouri and middle and upper Mississippi Valleys, the upper Ohio Valley, the South Central States, and middle Atlantic area.

SNOW COVER, COLD WAVES, AND ZERO TEMPERATURES

The snow cover in central Michigan has a big influence on temperature, and a study was made of cold waves and zero and subzero readings in connection with the depth of snow. The study covers 15 consecutive years, from 1912 to 1926, inclusive.

One hundred and twelve cold waves occurred in the 15 years as follows:

Month	Number of cold waves	Snow cover	Per cent
January	41	41	100
February	25	25	100
March	18	14	78
November	9	4	44
December	19	17	89
Total	112	101	90

However, cold waves in March and November being more decided drops in temperature rather than real cold waves, may be excluded; this gives a percentage in favor of cold waves with a snow covering as 98%.

Even more conclusively is the vital importance of a snow cover shown in a study of the days with zero or below. Zero was not reached when the ground was bare. The depth of snow during the winter months does not seem to be important as long as it is above 3 inches; any unusually cold winter month with a number of very low readings was found to have a covering of snow, and the severity of the cold seemed to be increased by a depth of over 6 inches. Therefore in the following table it was so divided:

	T. to 6 inches	6 inches or over
Zero to −10°	101	52
−10° or lower	13	16
Total	114	68

It was also found that cold winter months were not followed by a cold spring unless there was a snow cover. The earlier the snow melts over the northern counties of Michigan the sooner does warm weather become established.—*R. M. Dole.*

METEOROLOGICAL SUMMARY FOR SOUTHERN SOUTH AMERICA, JANUARY, 1927

By J. B. NAVARETTE, Director

[Observatorio del Salto, Santiago, Chile]

January was characterized by a rather intense atmospheric circulation in the south and by stable weather in the central zone.

Important anticyclonic centers developed between the 1st and 4th, 7th and 11th, 17th to 19th, and 21st to 31st in the far south; these days had characteristically good weather in general, with strong southerly winds of 1,000 to 1,500 meters per minute between the coasts of Chiloe and Arauco, and high temperature in the central zone. The maxima were from 33° C. to 35° C. in the shade.

Atmospheric depressions crossed the far south during the 5th and 6th, 12th to 14th, and 16th to 20th. The rains were limited in general to the region between Valdivia and Chiloe, precipitation varying from 10 to 30 mm., while it rained occasionally as far north as Concepcion.—*Transl. B. M. V.*

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SOLAR OBSERVATIONS

SOLAR AND SKY RADIATION MEASUREMENTS DURING FEBRUARY, 1927

By HERBERT H. KIMBALL, Solar Radiation Investigations

For a description of instruments and exposures and an account of the method of obtaining and reducing the measurements, the reader is referred to the REVIEW for January, 1924, 52:42, January, 1925, 53:29, and July, 1925, 53:318.

From Table 1 it is seen that solar radiation intensities averaged close to normal at Washington, D. C., and Lincoln, Nebr., and slightly below normal at Madison, Wis.

Table 2 shows a deficiency in the total solar radiation received on a horizontal surface from the sun and sky at Washington and close to the normal amount at Madison and Lincoln. No record was obtained at Twin Falls during February, as the pyrheliometer was undergoing repairs. The altitude of the pyrheliometer at that station is reported by the official in charge to be about 1,200 meters instead of 1,300 as given in the January REVIEW.

No skylight-polarization observations were obtained at Madison, Wis., as the ground was covered with snow throughout the month. At Washington, measurements made on three days give a mean of 61 per cent with a maximum of 62 per cent on the 17th. These are close to average values for Washington in February.

TABLE 1.—*Solar radiation intensities during February, 1927*

Washington, D. C.

[Gram-calories per minute per square centimeter of normal surface]

Date	Sun's zenith distance: 8 a.m.	78.7°	75.7°	70.7°	60.0°	0.0°	60.0°	70.7°	75.7°	78.7°	Noon
	75th mer. time	Air mass: A. M.					P. M.				Local mean solar time
	c.	5.0	4.0	3.0	2.0	1.0[1]	2.0	3.0	4.0	5.0	c.
	mm.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.	mm.
Feb. 2	3.99	0.69	0.79	0.98	1.25	1.57	1.17	0.96	0.89	0.80	3.81
7	4.17	0.62	0.70	0.87	1.07	.....	1.10	0.82	.....	.....	4.17
10	4.75	.....	.....	.....	1.08	.....	.....	.....	.....	.....	4.37
11	3.63	.....	0.73	0.94	1.22	1.64	1.28	.....	.....	.....	2.16
17	7.29	0.85	0.97	1.08	1.32	1.62	.....	.....	.....	.....	5.79
26	5.36	0.77	0.89	1.04	1.26	1.52	1.26	.....	.....	.....	2.49
Means	.....	0.73	0.82	0.98	1.20	1.59	1.20	(0.89)	(0.89)	(0.80)	.....
Departures	.....	+0.02	+0.01	±0.00	+0.03	.....	+0.01	−0.08	+0.05	+0.03	.....
Madison, Wis.											
Feb. 3	5.56	.....	.....	.....	1.31	.....	1.41	1.18	.....	.....	5.16
9	1.52	.....	.....	.....	.....	.....	1.35	.....	.....	.....	1.78
10	1.24	1.04	1.15	1.28	1.43	.....	.....	.....	.....	.....	1.19
11	2.26	.....	.....	.....	1.24	.....	.....	1.18	.....	.....	3.15
12	1.78	1.02	1.11	1.25	1.42	1.62	.....	.....	.....	.....	1.78
15	1.88	.....	.....	1.08	.....	.....	.....	.....	.....	.....	4.95
18	0.86	.....	.....	.....	1.43	.....	1.49	1.21	.....	.....	1.37
19	1.52	.....	0.87	1.07	1.32	.....	1.29	.....	.....	.....	2.06
21	2.36	.....	.....	0.95	1.24	.....	.....	.....	.....	.....	3.00
24	3.99	.....	.....	1.24	1.40	1.58	1.36	.....	.....	.....	3.99
Means	.....	(1.03)	1.04	1.14	1.35	(1.60)	1.37	1.19	.....	.....	.....
Departures	.....	+0.09	−0.07	−0.09	−0.02	.....	+0.01	+0.01	.....	.....	.....
Lincoln, Nebr.											
Feb. 1	2.87	1.02	1.15	1.28	1.43	1.58	.....	.....	.....	.....	3.00
9	1.24	.....	.....	.....	.....	.....	1.36	.....	1.11	0.96	1.37
10	1.78	.....	0.93	1.15	1.40	.....	1.40	1.27	1.08	1.01	2.62
11	2.62	.....	.....	1.03	1.35	.....	.....	1.23	0.95	.....	2.74
18	0.74	1.08	1.21	1.35	1.51	1.69	1.39	1.01	0.96	0.91	0.91
23	4.17	.....	0.98	1.13	1.38	.....	1.38	1.17	1.13	1.01	3.99
24	4.17	.....	.....	.....	.....	.....	1.34	.....	.....	.....	4.57
25	3.30	1.00	1.11	1.34	1.45	1.58	.....	.....	.....	.....	3.45
Means	.....	1.03	1.08	1.21	1.42	1.62	1.37	1.17	1.06	0.97	.....
Departures	.....	+0.06	+0.03	+0.01	+0.04	.....	+0.02	±0.00	+0.01	+0.08	.....

[1] Extrapolated.

TABLE 2.—*Solar and sky radiation received on a horizontal surface*

[Gram-calories per square centimeter of horizontal surface]

Week beginning—	Average daily radiation: Washington	Madison	Lincoln	Chicago	New York	Average daily departure from normal: Washington	Madison	Lincoln
1927	cal.	cal.	cal.	cal.	cal.	cal.	cal.	cal.
Jan. 29	198	187	233	139	154	+6	−4	−4
Feb. 5	175	199	253	139	117	−32	−10	+20
12	186	200	243	127	119	−39	−32	−45
19	169	302	333	244	141	−78	+52	+23
Deficiency since first of year on Feb. 25						−1,087	−406	−553

PHOTOHELIOGRAPHIC OBSERVATIONS

[Communicated by Capt. EDWIN T. POLLOCK, Superintendent, United States Naval Observatory. Data furnished by the Naval Observatory in cooperation with Harvard, Yerkes, and Mount Wilson Observatories]

METHODS USED TO OBTAIN POSITIONS AND AREAS OF SUN SPOTS

UNITED STATES NAVAL OBSERVATORY, WASHINGTON, D. C.

The measured positions and areas of solar spots and groups herewith published were made from negatives taken with the 40-foot horizontal photoheliograph of the United States Naval Observatory. The 40-foot objective (12.192 m.) is of 5 inches (12.7 m.) aperture, corrected for actinic rays, and the solar image at the focus of the instrument is about 4¼ inches (10.8 cm.) in diameter. It is used in conjunction with an unsilvered plane mirror to throw the solar light in the proper direction. Photographs are taken daily near noon, weather permitting.

Dry plates 7 inches square are employed, coated with a slow lantern-slide emulsion, and are backed with a paste of Winsor and Newton moist lampblack before exposure, to prevent halation. Just in front of the photographic plate hangs a plumb line of fine wire which casts a sharp shadow image upon the solar disk during exposure. This exposure is made by a drop shutter with an adjustable slit located just in front of the plate. The vertical image of the plumb line impressed on the negative, together with the eastern standard time of exposure, furnish data for orientation of the plate.

An ingenious instrument recently devised by Mr. Watts and Miss Lamson, of the Naval Observatory, and constructed by the instrument maker at the observatory, was used for these measures.

Transparencies having the sun's outline and heliographic coordinates ruled for each 10°, corresponding to the period of observation, are used with this instrument. From these transparencies the heliographic latitudes and longitudes of the solar markings may be directly read, after setting for the proper position angle of the sun's axis at the time of observation. Areas to the nearest whole square degree are measured similarly, on a separate reticule line chart. Foreshortening is allowed for on this chart as the solar limb is approached, so that the true area is determined. Unless the larger spots comprising a group indicate individuality, the position measured is referred to the mean center of the group as a whole. With respect to position and area of spots, both umbra and penumbra are here considered as an entity. Faculæ are not included in these measures. For well defined objects not too near the limb these positions are probably accurate to ±0.5°.—*G. H. Peters.*

HARVARD COLLEGE OBSERVATORY

The solar image is photographed every clear day at the Harvard Astronomical Laboratory, using the Clark 8-inch equatorial with negative-enlarging lens to produce an equivalent focus of 553 centimeters, giving a solar image of about 6 centimeters diameter with a scale of 1 millimeter, representing about 14,500 miles or 24,000 kilometers near the center of the solar image. The telescope carries a special solar attachment for photographing the image, using a focal plane curtain shutter which may be adjusted in speed and opening to produce any exposure down to one-thousandth of a second. A color screen, selected to best suit the objective, was manufactured for us by the Eastman Kodak Co. The color curve of the lens was first determined and used as a basis for the selection of the proper filter. The filter is placed in the plate holder immediately in front of the plate. The objective is provided with a stop holder which makes possible the diminution of the light received on a clear day. An aperture of about 6 inches is used with an exposure of one five-hundredth of a second on a "Cramer contrast" plate.

The east and west line is located from the short dimension edge of the 4 by 5 inch plate, this being squared with the camera, which is carefully oriented by trails and clamped in place on the draw tube of the telescope.

The plates are developed in hydroquinone, and when fixed, dried, and labeled are ready for measurement. As the method of measuring x's and y's of the sun spots and reducing the same to the heliographic position by the usual trigonometrical computation is long and tedious and of greater accuracy than the nature of the problem seems to require or allow, a modification of the projective method devised by Hale and used at Yerkes and Mount Wilson has been adopted which has perhaps some merits as regards simplicity and convenience of operation.

In place of the steel ball used by Hale, we make use of a well-made white globe with celluloid finish, upon which marks can be made and erased with perfect satisfaction. The globe is 8 inches in diameter and is mounted in a supporting ring graduated into degrees. This supporting ring in turn is mounted in a fork support which may be adjusted about a vertical axis by the amount necessary to allow for the tip of the solar pole to or from the earth. The angle of inclination of the sun's axis to the fundamental plane perpendicular to the line of sight is taken from the Ephemeris, as is also the position angle of the solar axis with respect to the north and south line.

The adjustment of the axis of the globe for the latter inclination or position angle with the north and south line is effected by turning the supporting ring in the fork which supports it. The graduations on a horizontal circle facilitate the adjustment of tilt with respect to the fundamental plane, whereas the graduations of the supporting ring of the globe itself allow for accurate orientation of the axis in position angle.

When the globe has once had its axis adjusted to correspond to that of the sun for the day in question, the photographic negative is placed in the projecting lantern and the image of the negative solar disk cast upon the globe. The size of the image is made to exactly fit the globe by adjusting the distance of the globe from the lantern in conjunction with the focusing of the projecting lantern itself in the usual way. In this way compensation is provided for the change in the apparent diameter of the sun throughout the year.

With the solar image projected onto the globe the centers of all visible spots can be accurately located with a sharp-pointed pencil and numbered in any sequence or date desired. It is usually possible to mark on the globe the positions of spots from several negatives taken on successive days without confusion.

As soon as all the spots have been thus located for a given day or series of days, a solar meridian is carefully drawn along the edge of the brass supporting ring which will make possible the resetting of the globe to the same identical position or for any other longitude of sun's center that may be desired. The globe thus marked together with its supporting ring is then removed from the supporting stand and placed in a precision mounting accurately machined and with a horizontal circle reading by degrees from 0° to 360°. The globe and ring is placed in the stand so that the axis of the globe is perpendicular to the horizontal circle. The position of the pole is read directly from the brass supporting ring.

The globe is then rotated in its stand until each spot in turn is brought under the meridian ring from which the heliographic latitude is at once read directly to the nearest degree and by estimation to the nearest tenth of a degree. The difference in heliographic longitude is obtained at the same time by noting the movement of the fiduciary meridian with respect to the horizontal circle, reading again directly to the nearest degree and by estimation to the nearest tenth of a degree. The values published are referred to the meridian passing through the center of the sun's disk and are expressed to the nearest degree. By such an arrangement it is possible to make several independent set-ups and thus automatically check the determination of the position and reduce the probable errors of reading as desired.

It is sufficient to add that we have found such a method and arrangement greatly superior to the use of any of the several sets of sheets giving heliographic coordinate systems for certain limiting dates both as regards accuracy and facility in obtaining the desired data.

For determining the areas of spots, concerning which it is understood that areas in terms of the sun's hemisphere are desired, a plane metal disk is used in place of the globe as a projecting screen. This disk is covered with a sheet of coordinate paper, which has ruled upon it a circle 8 inches in diameter. The solar image is made to fill the 8-inch circle and the area of a spot is estimated in terms of the number of millimeter squares which are covered by the umbra and penumbra of the spot. These areas are then corrected for foreshortening by multiplying by the secant of the angular distance of the spot from the center of the disk, the corrected areas being then divided by the area of the hemisphere in square millimeters $\times 10^{-6}$ to give the actual area in millionths of the sun's hemisphere.

Experiments are in progress for the measurement of sun-spot areas by the use of a modification of the thermoelectric photometer,[1] but ways of eliminating or correcting for the varying background absorption have not yet been completely and satisfactorily worked out.—*H. T. Stetson.*

YERKES OBSERVATORY

At the Yerkes Observatory the direct photographs of the sun are taken with the 12-inch Kenwood equatorial diaphragmed down to an aperture of 3 inches. The focal length of the telescope is 5.49 meters, so that the solar image is about 51 millimeters in diameter. Sharp images are obtained with the lens, which is corrected for visual rays, by using a yellow filter and Eastman process plates. Short exposures are given by means of a plate shutter, operated by a spring, and reduced to a slit about 3 millimeters wide, over which the glass filter is fastened. The image was formerly oriented by means of the shadow of a metal wire stretched across the image of the sun; before the exposure the wire was oriented by projecting on it the image of the sun and examining on a ground glass to see if the wire was parallel to the diurnal motion of the sun's limb. Difficulty was encountered in keeping the metal wire perfectly straight. Since March 1, 1927, the orientation of the camera is obtained by using the edge of the shutter instead of a metal wire. This edge has been made exactly perpendicular to the direction of motion of the slit. A small opaque spot on the filter appears as a fine straight line on the negative, thus indicating the north-south direction.

For measuring the negatives they are projected by an arc lamp on the 6-inch graduated disks prepared by the Stonyhurst Observatory for that purpose. (Journal of the British Astronomical Association, vol. 18, p. 26, 1907.) The constants for the date determine the disk to be used and the rotation to be given to the negative so that one can read directly the latitudes, the differences of longitude between the spot and the central meridian, and also the areas in square degrees.—*George Van Biesbroeck.*

[1] Astrophysical Journal 43:253:58:36.

MOUNT WILSON OBSERVATORY

The positions and areas of sun spots furnished by the Mount Wilson Observatory for publication in the MONTHLY WEATHER REVIEW are taken from the daily records of the magnetic polarities of sun spots. These records are made at the 150-foot telescope by projecting the image of the sun, mean diameter 42.8 centimeters, upon a sheet of paper and sketching the spots. The heliographic latitude and longitude of each group is read from a disk on which the circles of solar longitude and the parallels of latitude have been drawn for every 10 degrees. Twenty of these disks are available for different diameters of the image and different values of the heliographic latitude of the sun's center.

To determine the areas a réseau, ruled to square millimeters, is placed on the sketch and the area of each group counted in square millimeters. The areas are then reduced to millionths of the visible hemisphere, taking into account the actual diameter of the image. The distance of each group from the center of the disk is then measured and the projection factors obtained to correct the areas for foreshortening.

The solar photographs made at the 60-foot tower telescope, sun's mean diameter 17.1 centimeters, are compared with the sketch and, if any spots have been omitted, they are measured on the photograph by methods similar to those described in the *Greenwich Photoheliographic Results*.—*Seth B. Nicholson.*

Positions and areas of sun spots

Date	Eastern standard civil time	Heliographic		Area	
		Longitude	Latitude	Spot	Group
1927	*Hr. min.*	°	°		
Jan. 1 (Mount Wilson.)	13 35	−65.0	+20.0	39	
		−21.0	+9.5		385
		+7.5	−8.0		626
		+49.0	−11.0	10	
		+62.0	+19.0		7
Jan. 13 (Mount Wilson.)	14 20	−78.0	+27.0		594
		−59.0	−20.0		32
		+19.0	−20.0	4	
		+31.0	+8.0		255
		+40.0	−17.5		197
		+66.0	+21.0	9	
		+70.0	−16.0		499
Jan. 14 Mount Wilson.)	13 40	−87.0	−13.0	199	
		−62.0	+26.0		740
		−43.0	−18.0		8
		+45.0	+8.0		19
		+55.0	−17.0		16
		+83.0	−18.0		59
Jan. 23 (Mount Wilson.)	17 30	−57.0	−6.0		55
		+30.0	+34.0		181
		+30.5	−15.0		427
		+62.0	+26.0		529
		+65.0	+10.0		35
Jan. 28 (Mount Wilson.)	11 5	−84.0	−12.0	44	
		−71.0	+12.0		246
		−58.0	−17.0		21
		−7.0	−9.0		25
		+7.5	−8.5		44
		+41.0	−11.0		5
		+58.0	+13.0		10
Feb. 1 (Naval Observatory.)	11 54	−67.5	+22.0	154	
		−50.0	+22.0		62
		−38.5	−28.0		247
		−35.0	−13.5		309
		−17.0	+11.0		185
		−7.0	−15.5		370
		+34.5	−16.5		494
Feb. 2 Naval Observatory.)	11 51	−79.0	+11.0	123	
		−70.0	+17.0	93	
		−53.5	+24.0		62
		−45.0	+24.5		31
		−27.5	−15.5		309
		−27.0	−27.5		154
		−17.5	−11.0	31	
		−6.0	+13.5		46
		0.0	+11.0	108	
		+6.0	−15.5		463
		+47.5	−17.5		525

Positions and areas of sun spots—Continued

Date	Eastern standard civil time	Heliographic		Area	
		Longitude	Latitude	Spot	Group
	Hr. min.	°	°		
Feb. 3 (Naval Observatory.)	11 47	−80.0	−15.0	154	
		−64.0	+9.5	123	
		−57.5	+15.0	154	
		−40.5	+22.5	15	
		−32.0	+24.5		26
		−18.0	+23.0		62
		−14.0	−16.0		309
		−14.0	−28.0		123
		−4.5	−11.0	31	
		+8.0	+15.5	10	
		+12.5	+11.0	123	
		+19.5	−16.0		463
		+61.0	−17.5		525
Feb. 4 (Naval Observatory.)	13 47	−70.0	−14.0		370
		−49.5	+10.0	93	
		−42.5	+15.5		93
		−17.0	+25.0	31	
		−5.5	+24.0	15	
		−4.0	−28.0		26
		+1.0	−16.0		370
		+4.5	−28.0		62
		+10.5	−11.0		15
		+28.0	+11.0	93	
		+35.5	−15.0		278
		+75.0	−18.0		463
Feb. 5 (Harvard.)	11 21	−51.	−13.		362
		−34.	+10.	73	
		−28.	+15.		164
		+12.	−14.		438
		+15.	−26.	56	
		+38.	+9.	174	
		+46.	−14.		198
Feb. 6 (Mount Wilson.)	18 20	−67.0	+13.0	10	
		−43.0	−8.0		10
		−40.0	−14.0		781
		−24.5	+7.5		14
		−24.0	−12.5		26
		−20.0	+10.0	83	
		−11.0	+16.0		471
		+12.0	+26.0		2
		+30.0	−17.0		518
		+33.0	−28.0		65
		+58.0	+12.0	133	
		+67.0	−13.0	204	
Feb. 7 (Naval Observatory.)	11 53	−56.0	+14.0		31
		−33.0	−7.5		62
		−30.5	−14.0		556
		−15.5	−12.5		62
		−11.0	+9.0		108
		−1.5	+16.0		309
		+29.0	+25.0		46
		+39.0	−17.5		370
		+43.0	−28.0		46
		+66.0	+11.0	123	
		+78.5	−13.0		154
Feb. 8 (Harvard.)	10 31	−79.	−23.	175	
		−53.	+20.		52
		−16.	−12.		557
		−17.	−6.		72
		0.	−12.	49	
		+3.	+6.		76
		+4.	+9.	46	
		+12.	+14.		261
		+40.	+22.		52
		+47.	−18.	362	
		+51.	−30.	73	
		+78.	+9.	170	
Feb. 9 (Naval Observatory.)	11 48	−67.0	−27.5	123	
		−4.5	−8.0		93
		−4.0	−15.0		463
		+16.0	+5.5		278
		+18.5	+10.0	46	
		+26.5	+17.0		216
		+37.0	+26.5		31
		+58.0	+25.5		123
		+64.0	−17.0		309
		+70.0	−29.0	46	
Feb. 10 (Naval Observatory.)	11 48	−54.5	−28.0	123	
		+8.5	−8.0		93
		+9.5	−15.5		432
		+20.0	+5.5		247
		+31.5	+10.0	46	
		+40.0	+17.0		154
		+69.0	+25.0	123	
		+82.0	−17.0		309
		+83.0	−29.0	62	
Feb. 11 (Naval Observatory.)	11 47	−83.0	−13.0	123	
		−41.0	−28.0	123	
		+24.0	−8.0		309
		+24.0	−15.0		370
		+44.0	+5.5		247
		+45.5	+10.0	62	
		+51.0	+16.0		278
		+69.5	+18.0	62	
Feb. 12 (Naval Observatory.)	11 56	−68.0	−13.0	123	
		−28.0	−28.5		123
		+37.5	−8.0		185
		+39.0	−13.5		401
		+58.5	+8.5		154
		+59.0	+10.5	46	
		+70.0	+17.5		123

Positions and areas of sun spots—Continued

Date	Eastern standard civil time	Heliographic		Area	
		Longitude	Latitude	Spot	Group
	Hr. min.	°	°		
Feb. 15	11 45	−48.0	+32.5		93
(Naval Observatory.)		−37.0	+11.0		123
		−29.5	−13.5	123	
		+11.0	−28.5	93	
		+17.5	+13.0		31
		+79.5	−13.0	309	
Feb. 16	11 31	−37.0	+32.0		62
(Naval Observatory.)		−23.0	+10.5		216
		−17.0	−14.0	123	
		+24.5	−27.0	77	
		+34.0	+15.0	31	
Feb. 17	11 45	−62.5	+12.0		185
(Naval Observatory.)		−25.0	+34.0	31	
		−8.0	+10.5		154
		−4.5	−13.5		123
		+37.5	−27.5	93	
		+49.0	+14.0	31	
Feb. 18	12 1	−52.0	+12.5		31
(Naval Observatory.)		−49.0	−9.5		31
		−44.0	+11.5		93
		−12.0	+34.0	31	
		+4.5	+10.5		123
		+9.5	−13.5	108	
		+50.0	−27.5	93	
Feb. 19	15 45	−33.0	−10.5		73
(Mount Wilson.)		−32.0	+12.0		17
		−1.0	+18.0		1
		+3.0	+34.0		13
		+20.0	+10.0		27
		+25.0	−13.0		124
		+67.0	−29.0	24	
Feb. 20	13 50	−85.0	+13.0		83
(Mount Wilson.)		−21.0	−10.0		154
		−19.0	+12.0		12
		+15.0	+34.0	10	
		+33.0	+11.0		13
		+36.0	−14.0		137
		+79.0	−28.0	36	
Feb. 21	12 36	−68.0	+13.5	123	
(Naval Observatory.)		−59.5	−26.0	31	
		−6.5	−9.5		154
		+46.0	+15.0	15	
		+49.0	−13.5	108	

Positions and areas of sun spots—Continued

Date	Eastern standard civil time	Heliographic		Area	
		Longitude	Latitude	Spot	Group
	Hr. min.	°	°		
Feb. 22	11 45	−55.0	+13.5		123
(Naval Observatory.)		−47.5	−26.0		31
		−30.0	+11.5		46
		+7.0	−10.5		185
		+7.0	−18.5		31
		+57.5	+12.5	31	
		+60.5	−14.0	108	
Feb. 23	10 27	−66	−13	41	
(Harvard.)		−36	+14		58
		+20	−9		210
		+73	−15	139	
Feb. 24	11 48	−85.0	−18.0	139	
(Naval Observatory.)		−67.0	−18.5	15	
		−27.0	+14.0		46
		−3.0	+11.0		46
		+34.5	−10.5		123
Feb. 25	14 20	−66.0	−18.0	147	
(Mount Wilson.)		−65.0	−25.0	21	
		−53.0	−18.0	16	
		−13.0	+13.0		40
		−12.0	−27.0		4
		−2.0	−20.0	4	
		+14.0	+11.0		18
		+54.0	−12.0		63
Feb. 26	11 46	−52.5	−18.0	139	
(Naval Observatory.)		−40.5	−18.0	15	
		+1.0	+14.0		77
		+12.0	−18.0		31
		+66.0	−9.5		62
Feb. 27	11 46	−64.0	+22.0	31	
(Naval Observatory.)		−42.0	−18.0		123
		−37.0	−24.5	10	
		+12.5	+14.0		123
		+17.5	−26.5		31
		+28.0	−17.5		15
Feb. 28	11 45	−54.0	+22.0		62
(Naval Observatory.)		−27.5	−18.0		139
		−23.5	−12.0		31
		+27.0	+15.0		123
		+33.0	−25.0		26

AEROLOGICAL OBSERVATIONS

By WELBY R. STEVENS

With the exception of the mean temperatures at 4,500 meters above Ellendale, mean free-air temperatures were above normal at all aerological stations. Departures aloft were in general of the same order of magnitude as at the surface.

Humidity departures were unimportant, although they were mostly below normal at Broken Arrow and Royal Center and above normal at Groesbeck.

Vapor pressure departures were mostly positive.

North of the thirty-seventh parallel and east of the one hundredth meridian the general wind resultants near the surface were W. to NW.; south of this latitude they were W. to SW.; west winds prevailed aloft east of the one hundredth meridian. On the north Pacific coast southerly winds prevailed to 3,000 meters, above which they shifted to northerly; on the south Pacific coast southerly winds were general to 500 meters, above which they shifted to northerly. The resultants show that there was an excess of southerly component over the normal (or less northerly component) corresponding to the well-defined excess of mean temperature over practically the entire country. (See Chart III.) Perhaps the excess of mean temperature was due more to the lack of severe cold waves than deviation of resultant winds from normal. Correlation between wind direction and temperature is not perfect, as has been pointed out before, since southerly winds often transport cold air masses and northerly winds warm masses. Resultant velocities were about normal. The table below shows winds of 40 m. p. s. or more observed during the month.

Date	Station	Velocity (m. p. s.)	Altitude (m. s. l.)
1	Cheyenne	52 WNW	4,000
2	Washington	54 WNW	4,500
3	Ellendale	40 NW	5,000
12	Medford	44 N	5,750
13	Medford	45 NE	6,750
20	Cheyenne	60 WNW	3,250
24	Cheyenne	40 WNW	4,000
26	Atlanta	40 W	4,000
28	Due West	49 W	4,750

The unusually high WNW. winds observed at Cheyenne are of particular interest, since verifying pilot-balloon ascents were made on two different days during the month, when velocities considerably above normal were observed. In each case the verifying ascent showed the same general character as the first.

On the 1st and 20th Cheyenne was under the influence of almost identical pressure conditions. A LOW of great intensity was moving inland from the north Pacific coast with a rather weak area of high pressure over Colorado. On the 24th the situation was quite different. An area of high pressure was moving in from the NW. By the morning of the 25th it had overspread the entire Rocky Mountain region and the Plains States. Relative to the high winds frequently observed over Cheyenne, the Official in Charge says:

> Perhaps the most level pass across the Rockies lies in southern Wyoming, with an elevation of 6,000 to 7,000 feet; on either side are ranges 9,000 to 12,000 feet; however, the Laramie Mountains form a barrier of lesser height than the ranges across the east end

of this pass, and the crest of the pass over these mountains is from 2,000 to 3,000 feet higher than the local office; it is believed this topography together with the distribution of pressure may be the cause of the freak winds, as it is almost invariably observed that if there is a LOW over Alberta, or even over British Columbia and Washington with a toe extending into northern Wyoming in combination with a HIGH over western Colorado or Utah, or even Nevada and Arizona, unusually high winds are recorded for elevations of 2,000 to 4,000 feet. If pressure conditions are reversed, the HIGH being over the Dakotas, Montana, northern Wyoming, and sometimes as far westward as Minnesota, also sometimes over Idaho with a toe extending into northern Wyoming, in combination with a LOW over western Colorado, Utah, and even as far distant as Arizona and southern California, there seems to be a calm or marked falling off of velocity at the same altitude, almost invariably.—*Geo. W. Pitman.*

Kite flights were made at Broken Arrow and Groesbeck on the morning of the 17th within the southern sector of a well-developed cyclone which was central over southern Kansas. The flight at Groesbeck shows an unstable lapse rate to 693 meters, with a stable stratification to 2,254 meters, above which the gradient again became unstable to maximum altitude (2,545 meters). The wind direction changed from S. at the surface to WSW. aloft, the decidedly unstable rate from 2,254 meters to 2,545 meters being due to importation of colder air masses by the WSW. wind. A thunderstorm occurred NW. of the station during the flight.

The flight at Broken Arrow shows a stable rate on the ascent to highest altitude; however, on the descent temperature fell aloft with wind shifting from SW. and SSW. to WSW., while temperature at the surface rose, thus building up an unstable gradient.

A flight was made at Groesbeck on the 5th while rain was falling. It was followed by thunderstorms at a number of stations in eastern Texas. On this date Groesbeck was under the influence of a rather weak pressure system with light to moderate SSW. and SW. winds extending to at least 3,000 meters. Temperature had risen from the preceding day from the surface to 1,100 meters, while there was a fall from 1,250 meters to 2,700 meters. The air was near saturation from the surface to 3,000 meters and, coupled with a high lapse rate, a large amount of energy was available for convection, which soon resulted in the thunderstorms mentioned above.

TABLE 1.—*Free-air temperatures, relative humidities, and vapor pressures (mb.) during February, 1927*

TEMPERATURE (°C.)

Altitude, m. s. l. (m.)	Broken Arrow, Okla. (233 m.) Mean	Broken Arrow, Okla. (233 m.) Departure from 9-yr. mean	Due West, S. C. (217 m.) Mean	Due West, S. C. (217 m.) Departure from 6-yr. mean	Ellendale, N. Dak. (444 m.) Mean	Ellendale, N. Dak. (444 m.) Departure from 10-yr. mean	Groesbeck, Tex. (141 m.) Mean	Groesbeck, Tex. (141 m.) Departure from 9-yr. mean	Royal Center, Ind. (225 m.) Mean	Royal Center, Ind. (225 m.) Departure from 9-yr. mean	Washington, D. C. (7 m.)[1] (mean)
Surface	8.4	+2.9	12.3	+3.2	−8.2	+1.2	12.2	+1.7	2.7	+3.8	7.4
250	8.4	+3.0	12.1	+3.2			11.8	+1.6	2.5	+3.8	5.9
500	7.8	+3.5	11.4	+3.7	−8.4	+1.1	11.1	+1.8	0.6	+3.7	5.0
750	7.9	+4.3	10.7	+3.9	−7.7	+1.4	10.8	+1.8	−0.2	+3.6	3.7
1,000	7.9	+4.5	9.4	+3.4	−6.0	+2.3	11.1	+2.3	−0.6	+3.4	2.3
1,250	7.8	+4.7	8.0	+3.0	−4.9	+2.8	10.8	+2.6	−0.6	+3.8	1.5
1,500	7.0	+4.6	6.8	+2.8	−4.9	+2.7	9.4	+2.0	−1.4	+3.8	1.3
2,000	4.7	+3.9	4.0	+2.0	−7.2	+1.8	6.4	+1.1	−3.5	+2.7	0.1
2,500	2.1	+3.7	1.4	+1.8	−10.3	+1.0	3.2	+0.3	−5.8	+2.3	−2.0
3,000	−0.8	+3.5	−2.0	+0.9	−13.8	+0.2	1.0	+0.5	−9.0	+1.6	−5.9
1,500			−4.9	+0.7	−16.6	−0.1	0.6	+2.5	−12.2	+1.2	
,000			−7.9	+0.8	−19.1	+0.2	−2.5	+1.9	−15.2	+1.3	
,500			−9.7	+1.6	−22.3	−0.2	−6.4	+0.6	−18.4	+1.3	
5,000											

RELATIVE HUMIDITY (%)

Surface	68	0	70	+2	80	−1	77	+4	74	−3	65
250	68	0	70	+2			77	+6	74	−3	62
500	63	−2	65	0	79	−1	76	+8	73	−4	59
750	54	−7	62	−1	74	0	71	+7	68	−6	59
1,000	51	−5	62	+1	66	−3	63	+4	63	−6	59
1,250	48	−4	61	+1	59	−5	60	+4	54	−10	56
1,500	43	−7	58	0	55	−5	60	+8	52	−8	51
2,000	43	−3	55	0	56	−1	58	+11	48	−7	44
2,500	42	−3	52	−1	57	0	55	+11	45	−9	42
3,000	46	+2	59	+8	61	+5	52	+9	45	−10	47
3,500			49	+4	64	+10	49	+8	38	−17	
4,000			45	−3	62	+9	45	+7	34	−22	
4,500			47	−2	62	+9	53	+19	30	−22	
5,000											

VAPOR PRESSURE (*mb.*)

Surface	7.90	+1.53	10.57	+2.15	2.75	+0.08	11.74	+1.90	5.77	+1.16	6.74
250	7.84	+1.52	10.46	+2.16			11.45	+2.04	5.69	+1.15	5.81
500	6.90	+1.35	9.32	+1.91	2.69	+0.07	10.72	+2.23	4.93	+0.94	5.24
750	5.86	+1.00	8.71	+1.87	2.72	+0.25	9.62	+1.92	4.27	+0.66	4.78
1,000	5.72	+1.34	8.07	+1.71	2.71	+0.31	8.29	+1.45	3.67	+0.40	4.22
1,250	5.30	+1.35	7.25	+1.44	2.63	+0.31	7.37	+1.26	3.09	+0.19	3.88
1,500	4.50	+0.96	6.36	+1.10	2.38	+0.22	6.52	+1.23	2.79	+0.20	3.48
2,000	3.81	+1.00	4.82	+0.63	2.03	+0.23	5.06	+0.97	2.23	+0.15	2.72
2,500	3.06	+0.75	3.58	+0.26	1.69	+0.21	3.64	+0.38	1.71	+0.01	2.13
3,000	2.62	+0.73	3.09	+0.45	1.39	+0.24	2.76	+0.01	1.16	−0.19	1.67
3,500			1.95	+0.03	1.20	+0.32	2.53	+0.25	0.80	−0.23	
4,000			1.25	−0.31	0.98	+0.29	1.68	−0.11	0.63	−0.17	
4,500			1.09	−0.17	0.95	+0.39	1.68	+0.40	0.53	−0.17	
5,000											

[1] Naval Air Station, Anacostia, D. C.

TABLE 2.—*Free-air resultant winds (m. p. s.) during February, 1927*

Altitude (m.) m. s. l.	Broken Arrow, Okla. (233 meters) Mean Dir.	Mean Vel.	9-yr. mean Dir.	9-yr. mean Vel.	Due West, S. C. (217 meters) Mean Dir.	Mean Vel.	6-yr. mean Dir.	6-yr. mean Vel.	Ellendale, N. Dak. (444 meters) Mean Dir.	Mean Vel.	10-yr. mean Dir.	10-yr. mean Vel.	Groesbeck, Tex. (141 meters) Mean Dir.	Mean Vel.	9-yr. mean Dir.	9-yr. mean Vel.	Royal Center, Ind. (225 meters) Mean Dir.	Mean Vel.	9-yr. mean Dir.	9-yr. mean Vel.	Washington, D. C. (34 meters) Mean Dir.	Mean Vel.	7-yr. mean Dir.	7-yr. mean Vel.
Surface	S. 4°W.	0.8	N. 37°W.	0.4	S. 54°W.	1.7	S. 81°W.	1.9	N. 66°W.	3.2	N. 47°W.	2.3	S. 78°W.	1.2	S. 82°W.	0.7	N. 78°W.	1.4	S. 84°W.	1.9	N. 74°W.	1.5	N. 49°W.	1.6
250	S. 8°W.	1.0	N. 56°W.	0.3	S. 56°W.	2.2	S. 82°W.	2.2					S. 52°W.	2.0	S. 66°W.	1.0	N. 70°W.	1.7	S. 82°W.	2.2	N. 70°W.	4.1	N. 66°W.	2.4
500	S. 8°W.	3.1	S. 50°W.	0.8	S. 71°W.	4.5	S. 81°W.	4.1	N. 73°W.	3.4	N. 52°W.	3.4	S. 33°W.	3.5	S. 47°W.	1.9	S. 78°W.	2.5	S. 60°W.	3.7	N. 64°W.	6.0	N. 68°W.	5.2
750	S. 24°W.	4.2	S. 55°W.	2.0	S. 72°W.	6.2	S. 78°W.	5.4	N. 78°W.	4.8	N. 58°W.	4.6	S. 44°W.	4.4	S. 53°W.	2.6	S. 87°W.	3.9	S. 71°W.	5.4	N. 62°W.	7.8	N. 65°W.	6.6
1,000	S. 37°W.	5.4	S. 65°W.	2.9	S. 86°W.	8.2	S. 82°W.	6.8	N. 73°W.	5.3	N. 57°W.	5.4	S. 52°W.	5.2	S. 62°W.	3.8	N. 75°W.	5.6	S. 79°W.	6.6	N. 71°W.	8.7	N. 70°W.	8.0
1,250	S. 49°W.	6.8	S. 85°W.	3.8	N. 88°W.	10.4	S. 85°W.	8.3	N. 72°W.	6.2	N. 57°W.	6.3	S. 59°W.	6.8	S. 72°W.	4.9	N. 72°W.	6.8	S. 86°W.	7.6			N. 68°W.	10.2
1,500	S. 46°W.	7.1	S. 89°W.	4.7	N. 88°W.	11.9	S. 87°W.	10.1	N. 73°W.	6.8	N. 60°W.	7.3	S. 56°W.	8.8	S. 77°W.	6.3	N. 67°W.	8.2	N. 88°W.	8.9	N. 73°W.	9.8	N. 68°W.	11.6
2,000	S. 50°W.	8.2	N. 85°W.	6.6	S. 86°W.	12.6	S. 89°W.	12.8	N. 72°W.	8.3	N. 62°W.	9.5	S. 62°W.	9.6	S. 86°W.	7.7	N. 67°W.	11.3	N. 85°W.	11.0	N. 68°W.	11.2	N. 72°W.	14.0
2,500	S. 53°W.	9.8	N. 85°W.	7.6	N. 87°W.	15.0	S. 89°W.	14.5	N. 72°W.	9.7	N. 64°W.	11.5	S. 70°W.	10.3	S. 87°W.	8.8	N. 75°W.	10.6	N. 85°W.	12.8	N. 70°W.	13.9	N. 76°W.	15.2
3,000	S. 60°W.	11.7	N. 84°W.	9.8	N. 89°W.	16.2	S. 87°W.	16.3	N. 75°W.	10.6	N. 66°W.	12.8	S. 67°W.	11.7	S. 86°W.	10.6	N. 77°W.	11.2	N. 87°W.	13.6	N. 82°W.	17.2		
3,500	S. 80°W.	9.9	N. 69°W.	10.9	S. 87°W.	16.4	N. 88°W.	17.1	N. 80°W.	11.6	N. 69°W.	13.0	S. 45°W.	12.0	W.	11.2	S. 75°W.	10.0	N. 88°W.	15.3				
4,000					W.	15.5	S. 88°W.	15.3	N. 86°W.	12.9	N. 68°W.	14.0	S. 45°W.	14.0	W.	12.1	S. 77°W.	21.2	S. 86°W.	15.1				
4,500					N. 68°W.	20.0	N. 82°W.	19.7	N. 82°W.	15.1	N. 68°W.	15.2	S. 45°W.	14.0	N. 86°W.	12.8	S. 77°W.	23.7	S. 77°W.	19.3				
5,000									W.	16.0	N. 88°W.	17.0												

WEATHER IN THE UNITED STATES

GENERAL CONDITIONS

The warmth of the month was the one outstanding feature of the weather. Precipitation in several localities was about double the normal. All in all it was a warm and moist month.—*A. J. H.*

CYCLONES AND ANTICYCLONES

W. P. DAY

Low-pressure areas were considerably more numerous than in January, and the more important depressions numbered 22. A majority of these were of Pacific origin or secondary developments over the Rocky Mountain region in conjunction with the Pacific types.

Twelve high-pressure areas were plotted, but only two were important as cold waves over any considerable area. These cold-air masses spread southeastward from Canada near the end of the first and second decades; otherwise temperatures were generally above the normal.

THE WEATHER ELEMENTS

By P. C. DAY, In Charge of Division

PRESSURE AND WINDS

The month was notably stormy on the Pacific coast, low pressure prevailing during much of the first week and again from the 12th to 25th, when precipitation occurred almost daily. It was heavy to excessive on a number of dates, particularly in southern California where from about the 14th to 16th the falls were among or actually were the greatest of record, causing much loss and damage by washing and flooding of roads and fields, destruction of bridges, etc. Considerable delay to traffic occurred due to impassable roads, and entire communities were without means of surface communication for varying periods. On account of the well-soaked condition of the soil prior to the occurrence of these heavy rains the run-off was heavy and all reservoirs were filled and ample supplies of water are assured.

Over the remainder of the country pressure was frequently low and there was considerable cyclonic activity, though this was confined mainly to the latter half. About the 13th low pressure developed in the Southwest and by the middle of the month stormy conditions had extended to the lower Lake region and precipitation had covered a wide area from the Rocky Mountains eastward, the rains being heavy to excessive over much of the Gulf region, with considerable snow from the middle Missouri Valley eastward to the Great Lakes and some sleet in southern New England. This storm moved into the St. Lawrence Valley during the 15th with generally lessened importance.

An important cyclone moved into the middle Plains by the morning of the 17th and by the following morning had advanced to the Middle Gulf States causing general precipitation over most central and southern districts from the Great Plains eastward, with local heavy rains in portions of the lower Mississippi Valley, New Orleans receiving nearly 7 inches in the 24 hours ending 8 a. m. of the 18th with an additional inch during the following day. This barometric depression gathered strength to the southward and on the morning of the 19th was central near the Georgia coast and heavy precipitation had occurred over portions of the east Gulf and South Atlantic States while lighter amounts had fallen over the remaining Atlantic coast area, the precipitation changing to heavy snow or sleet in the more northern localities. This storm moved northeastward somewhat off the coast during the following 48 hours, causing rain, sleet, or snow from the Ohio Valley eastward and northeastward, the precipitation changing to heavy sleet along the North Atlantic coast and to moderately heavy to heavy snow over the near-by interior districts. High winds and tides occurred during this time particularly along the New Jersey coast, where much damage resulted, while in some districts back from the coast heavy glaze greatly damaged overhead wire systems.

A slight barometric depression central in the lower Mississippi Valley on the morning of the 23d, moved eastward to the Carolina coast during the following 24 hours and was accompanied by some heavy rains over the east Gulf and South Atlantic States. Another slight depression, central over the Ohio Valley on the morning of the 25th, developed considerably by the following morning, when it appeared as two storms, one central over Lake Ontario and the other covering southern New England. These combined later and moved toward the Canadian Maritime Provinces. Precipitation from this storm covered most districts from the Mississippi River eastward, considerable snow occurred over the Great Lakes region and to the eastward, becoming heavy and wet toward the coast and causing some damage to wire systems. At the close of the month a cyclone of considerable importance had moved from the Southern Plateau to southern Texas, with precipitation rather general, but light, from the Rocky Mountains and western Great Plains southeastward to near the west Gulf coast, snow falling over the northern half of the area.

Anticyclones were mainly unimportant though on the 9th one of marked strength had entered the upper Missouri Valley and during the following few days moved southeastward to the Atlantic coast attended by generally fair and moderately cold weather over most districts from the Rocky Mountains eastward. Another of considerably smaller proportions entered Manitoba and the Dakotas on the morning of the 12th and moving eastward along the northern border during the following day or two brought some sharp temperature falls, particularly in the St. Lawrence Valley. Another anticyclone that gave promise of an extensive lowering of temperature over the Great Plains and central valleys and to the eastward, entered the Canadian Northwest and upper Missouri Valley on the 17th, with temperatures from 20° to 30° below zero near the center. It moved into the middle Missouri Valley during the following 24 hours and brought sharp temperature changes over the Great Plains and west Gulf region, the lowest temperatures of the month occurring over the States from Arkansas and Louisiana eastward on that and the following day or two as the effects of the anticyclone slowly extended eastward over the Southern States. From its main center over the middle Missouri Valley on the 18th, this anticyclone moved rapidly to the Northeast and on the 19th it had passed beyond the Great Lakes and to the southeastward of Hudson Bay. The sharp falls in temperature expected from this HIGH, which materialized in the far southern and northern districts, did not occur over the Central States from the Mississippi Valley eastward due to the development of cloudy, rainy conditions in that area.

The average pressure was nearly everywhere less than that normal for February, though in the Great Plains

and Southwest the variations from normal were small and in some localities the pressure was slightly higher than the normal, and like conditions existed over northeastern New England, the eastern Canadian Provinces, and in southern Florida. The average pressure was distinctly low over the far Northwest and in the southern Appalachian region.

Compared with January, 1927, the pressure averages were much lower in all parts of the country including Canada, the changes being particularly large along the North Pacific coast where usually February pressures are slightly higher than those for January.

The prevailing winds were mainly from southerly points over the Gulf and South Atlantic States, and over much of the Plateau and Pacific coast sections. Elsewhere they varied greatly.

High winds frequently prevailed over the Pacific coast, and occurred locally along the Atlantic seaboard, particularly along the Jersey coast on the 19th and 20th, when much damage resulted to buildings near the coast by undermining, etc. Over the interior there were frequent local storms, and damaging tornadoes occurred in northern Louisiana and near-by portions of Mississippi with a total loss of more than 40 lives and extensive property damage. The details concerning these and other storms appear at the end of this section.

TEMPERATURE

February as a whole was an abnormally warm month; practically every station in the United States and all reporting in Canada had monthly means above normal. In nearly all parts from the Mississippi Valley eastward, including also the West Gulf States, the averages were among the highest of record for February, while over many of the Southern States it was actually the warmest February in the period of record. Several stations in Alabama and portions of near-by States reported it as the warmest winter month in more than 50 years. As much of the country was distinctly warm in January, particularly in the South, and this area was also warmer than normal during December, a number of the Gulf States have had nearly, and probably in a few instances quite, the warmest winter of record. Chart III shows the extent of the temperature excess for the month.

The temperatures during the month were remarkably uniform for a winter month, particularly over the southern sections, Key West, Fla., having but one day with temperature below normal, while in other portions of the Gulf and South Atlantic States there were frequently not more than a few such days.

The warmest periods were the 3d and 4th in the East Gulf and South Atlantic States; the 16th to 18th in the Ohio Valley and Middle Atlantic States; the 20th to 24th along the northern border from Montana to New England, and at about the same time over much of the country from the middle and southern Plains west to the Pacific coast. In a few sections of the South Atlantic and East Gulf States the maximum temperatures of the month were the highest ever observed in February.

The lowest temperature, 48° below zero, was observed at an exposed locality in Wyoming, but temperatures of 25° to 35° below zero were observed at many points along the northern border and locally in the western mountains. Freezing temperatures or lower were recorded somewhere in all the States except Florida, where the lowest observed was 33°. At Norfolk, Va., the month was remarkable in that no temperature as low as freezing was observed, the first February occurrence of the sort in the 56 years of officially recorded observations.

PRECIPITATION

Considering the country as a whole the precipitation was above normal over more than half the States and in a few instances the amounts were far above, and locally the heaviest of record for February. This was notably the case in California, where the average precipitation was more than twice the normal, and locally in the south the falls were among the greatest of record. In the vicinity of San Diego precipitation was unusually heavy about the 10th to 16th, resulting in severe floods the damage or loss of many bridges, and the washing of fields and roads.

In the great central valleys the precipitation was very generally less than usual in February, and like conditions existed over most of the Atlantic Coast States.

SNOWFALL

Every State in the Union save Florida was visited by snow, though over much of the South the amounts were trifling and no important depths lay on the ground for an extended period, except over the more northern districts and in the mountain areas.

No widespread snow occurred on any single date, but there were considerable falls on the 5th and 6th from the upper Lakes westward to North Dakota and over the Northeastern States. About the 12th to 14th considerable snow fell over the northern districts, and some rather heavy falls occurred from Nebraska and near-by areas eastward to Michigan. There was some heavy snow, sleet, or glaze on the 19th and 20th over the Middle Atlantic States, causing much damage to overhead wires in portions of New Jersey and near-by areas. About the 26th–28th there was considerable snow over the eastern slopes of the Rocky Mountains including the adjoining plains from Nebraska southward to Oklahoma and northern Texas.

In the western mountain districts, snowfall was mainly above normal, particularly in the central and southern sections. Toward the north the falls were mainly somewhat less than normal.

At the close of the month the amount of stored snow in the high mountains was as a rule somewhat more satisfactory than for several years and the outlook for a sufficient supply of water for power and irrigation needs during the usual dry season was good.

RELATIVE HUMIDITY

The persistence of cloudy, rainy weather in many of the far Western States was reflected in the relative humidity which was far above normal in most of California and near-by States and generally above normal in other Western States save in Washington where there were some pronounced deficiencies.

Over practically all southern districts from Texas eastward and generally in the Ohio Valley and Atlantic Coast States relative humidity was uniformly above normal, but in the area between the Mississippi River and the Rocky Mountains varying conditions existed with a tendency to percentages below normal.

SEVERE LOCAL STORMS, FEBRUARY, 1927

[The table herewith contains such data as have been received concerning severe local storms that occurred during the month. A more complete statement will appear in the Annual Report of the Chief of Bureau]

Place	Date	Time	Width of path, yards [1]	Loss of life	Value of property destroyed	Character of storm	Remarks	Authority
Southern Iowa	4-5				$25,000	Heavy rains	Cofferdam washed out near Delhi, causing destruction of construction equipment; dirt roads impassable.	Official, U. S. Weather Bureau.
New York, N. Y., and vicinity.	4-5			4		High winds, sleet, and snow.	Considerable property damage in and around the greater city; many casualties from skidding cars.	Do. Herald-Times (New York).
Illinois (northern)	5					Floods	Railway tracks washed out near bureau; 23,000 acres inundated.	Official, U. S. Weather Bureau.
New Jersey	5					Sleet and glaze	Minor inconveniences and some property damage.	Do.
Toledo, Ohio	5					Ice	Severe storm but no damage of consequence reported.	Do.
Childress, Tex	7	6 p. m.	15 mi.		5,000	Heavy hail	Damage considerable over path 20 miles long	Do.
California (southern half)	10-17			18		Wind, rain, floods, and snowslides.	Damage principally by floods; orchards and citrus fruits severely injured; scores hurt and many driven from homes; most buildings in San Diego damaged.	Do.
Louisiana (southern)	12-13					Rain, wind, and small tornado.	Many telephone lines out of commission; some damage by flooding. Tornado occurred at Alexiusville.	Official, U. S. Weather Bureau; Times-Picayune (New Orleans, La.).
Millen (near), Ga	13	P. m.			1,000	High wind	Trees blown down; slight damage to dwellings; schoolhouse wrecked.	Official, U. S. Weather Bureau.
Harrisburg, Pa	13	P. m.				Ice	Slight damage to wires; streets and highways in bad condition; many accidents reported.	Do.
Ohio	13-14					Sleet	Storm quite severe at Ashland; character of damage not reported.	Do.
Lake Magdalene, Fla. (12 miles north of).	14					Small tornado	Small barn upset	Do.
Denver, Colo	15	P. m.				Wind	Grandstand partly unroofed; skylight broken	Post (Denver, Colo.).
Cairo, Ill	17					Thunderstorm and wind.	10 poles broken; trolley and street-lighting circuits severed; traffic delayed.	Official, U. S. Weather Bureau.
Colorado (southwestern)	17					Wind, snow, and snowslides.	Rail service crippled; buildings demolished by slides; 2 persons missing.	Post (Denver, Colo.)
Covington and Kenton, Tenn. (near).	17	P. m.				Electrical and wind.	One barn burned and others wrecked; some livestock killed.	Official, U. S. Weather Bureau.
Dodge City, Kans	17					Wind, snow, and dust.	Many motor cars stalled; streets blocked; 1 person lost for several hours.	Do.
Kansas (eastern)	17					Sleet	Only minor damage reported	Do.
Pleasant Hill, La. (west of)	17	5 p. m.	200	17	100,000	Tornado	Heavy property and timber damage over path 30 miles long; 20 persons severely injured.	Do.
Lake Bruin, La., to Alexander City, Ala.	17	7 p. m.		28		do	Much destruction of life and property at various points over a path more than 300 miles long. Many persons injured.	Official, U. S. Weather Bureau; Shreveport Times (La.); Times-Record (Fort Smith, Ark.).
Apalachicola, Fla., and vicinity.	18					High wind	Slight damage in city; highways obstructed by fallen trees; Government telephone line broken.	Official, U. S. Weather Bureau.
Brundidge, Ala	18	5 p. m.			40,000	Thunderstorm	A school, warehouse, and stores damaged	Do.
Galveston, Tex., and vicinity.	18				100,000	Gales	Many frame structures blown down; heavy damage to flying equipment at Fort Crockett; shipping delayed.	Official, U. S. Weather Bureau; San Antonio Daily Express (Tex.).
Madison County, Fla	18	P. m.			5,000	Tornadic wind	Considerable timber blown down; farm buildings, churches, and other property damaged.	Official, U. S. Weather Bureau.
Pennsylvania	18-21					Snow, sleet, and glaze.	Highways obstructed; rail transportation delayed; overhead wires broken; trees and small buildings damaged.	Do.
San Antonio, Tex. (near)	18				10,000	Wind	Seven planes wrecked; hangars and other planes damaged at Stinson Field.	San Antonio Daily Press (Tex.).
Atlantic seaboard and inland north of Virginia.	19-21			21		Wind, rain, sleet, snow, and tides.	Many buildings wrecked; foundations undermined; telephone and other wires damaged by glaze; heavy losses at sea; shipping delayed; many persons injured.	Official, U. S. Weather Bureau; The World (New York).
Oregon (western)	20-24					Heavy rains	Floods damaged railroads, highways, bridges, and lowland crops; also caused loss of logs, river craft, and house boats.	Official, U. S. Weather Bureau.
Baker, Oreg	21					Wind	Several windows broken; wire lines damaged	Do.
Helena, Mont	21					Violent gusts	Minor damage about city	Do.
Cleveland (near), Tenn	22			1		Electrical	No property damage reported	Do.
Beaumont, S. C	22	A. m.				Thunderstorm	Three persons injured by lightning	Do.
Goulds, Fla	24					Hail	Probable injury to tomato crop	Do.
Starke, Fla., and vicinity	25	2 p. m.	440		500	do	Crops injured	Do.
Maine, New Hampshire, and parts of Massachusetts.	25-26				200,000	Heavy snow and wind.	Public utilities sustain heavy losses; shipping menaced.	The Globe (Boston, Mass.).
New Jersey	26					Wind and tides	Storm similar to that of the 19th-21st, but less severe.	Official, U. S. Weather Bureau.
Garden City, Tex	28					Ice	Fruit considerably damaged	Do.

[1] "Mi." signifies miles instead of yards.

STORMS AND WEATHER WARNINGS

WASHINGTON FORECAST DISTRICT

On the morning of the 3d fresh to strong winds were forecast for the middle and north Atlantic coast in connetcion with a disturbance over the Upper Lakes. The disturbance moved very rapidly eastward during the next 24 hours and strong winds occurred, reaching gale force at times from Sandy Hook northward.

On the morning of the 6th southeast warnings were ordered from New London, Conn., to Portland, Me., in connection with a low-pressure center off the New Jersey coast, which was apparently increasing in intensity. The warnings were ordered down the same night, as the disturbance moved so rapidly northeastward that the winds shifted to west and were only fresh to strong.

The evening of the 13th northeast warnings were hoisted between Sandy Hook and Boston in connection with a disturbance near Hatteras; and on the following morning were extended northward to Eastport. Strong winds occurred as indicated in the warnings.

On the morning of the 16th a disturbance of considerable intensity was over Lake Michigan and southwest storm warnings were hoisted from Norfolk to Eastport. During the next 12 hours the disturbance decreased in intensity and warnings were lowered that night south of Delaware Breakwater. Winds were only fresh to strong.

On the morning of the 18th northwest storm warnings were ordered from Bay St. Louis, Miss., to Cedar Keys, Fla., and strong winds occurred. On the following morning, with a disturbance of considerable energy over Georgia, northeast storm warnings were hoisted from Wilmington, N. C., to Boston, for strong northeast winds and gales accompanied by rain and snow, and small craft warnings were ordered from Mobile to Key West. Northeast warnings were continued on the 20th from Boston to Sandy Hook and extended north of Boston to Eastport. Gales accompanied by snow and rain occurred generally along the middle and north Atlantic coast.

Southeast warnings were ordered the evening of the 25th from Sandy Hook to Eastport. On the afternoon of the following day these were changed to northwest, and were continued on the 27th, but ordered down the morning of the 28th. Strong winds and gales occurred substantially as indicated in the advices.

A cold-wave warning was issued for northwest Ohio on the morning of the 8th, and on the evening of that date for Kentucky; but, while the temperature fell, the change was gradual.

On the morning of the 14th heavy snow warnings were disseminated for northern New England.

Cold-wave warnings were ordered the evening of the 17th for Kentucky, Ohio, central and western Tennessee, and northern Mississippi, and on the following morning warnings were distributed for freezing temperature in the interior of Alabama and Mississippi and near freezing along the east Gulf coast. These warnings were verified, although temperatures did not fall quite as low as anticipated.

On the 19th warnings of freezing temperature nearly to the coast were issued for Georgia and Alabama and near freezing in extreme northern Florida. The temperatures indicated were not reached in places owing to a continuation of the cloudiness.

On the 20th the possibility of light frost was indicated for Alabama, Mississippi, and northwest Flordia, and light frosts occurred.

Heavy snow warnings were ordered for New England, western Pennsylvania, and New York on the morning of the 20th, and were verified, except in southeastern New York and southern New England, where the precipitation was partly in the form of rain.

Warnings for light frost were disseminated on the morning of the 26th for South Carolina, Georgia, southeast Alabama, and portions of northern Florida. These were verified.—*R. H. Weightman.*

CHICAGO FORECAST DISTRICT

February, 1927, in this district was unusually mild. At the same time precipitation was deficient almost generally. From the foregoing it would be natural to infer that the occurrence of weather conditions calling for special warnings was less frequent than usual. And such was the case.

Cold waves.—From time to time during the month a few cold waves of more or less limited geographic extent occurred in northern portions of the district, while one cold wave advanced southward across Kansas and northwestern Missouri. In the Middle Mississippi and Lower Ohio Valleys, however, the month passed without any cold waves. The dates on which cold-wave warnings were issued were the 3d, 7th, 8th, 11th, 14th, and 17th. The warnings on the 8th and 17th were the most general in scope. Conditions on the morning of the 17th appeared to be almost ideal for a general cold wave in the eastern and southern portions of the district, but both the HIGH and LOW concerned took unusual courses. These movements resulted in north and northeast winds in the southeastern States of the district and, although a marked fall in temperature occurred as a rule, the minimum temperatures fell many degrees short of the figure required.

Advisory warnings for Lake Michigan.—Disturbances affected Lake Michigan every two or three days in succession during most of the month, and it was necessary to issue advisory warnings for shipping on a number of occasions. The most severe storm was that of the 17th–18th, when strong north or northeast winds and gales prevailed over most of the Lake.

Stock warnings.—Only one warning of this character was issued, namely, that on the 17th for Kansas and Nebraska. This was in connection with the cold wave that occurred in those States on the 17th–18th.—*C. A. Donnel.*

NEW ORLEANS FORECAST DISTRICT

Areas of low pressure were dominant during the greater part of the month and temperatures averaged unseasonably high, but cold waves were not entirely absent. The most extensive cold wave occurred on the 17th–19th, and less extensive ones, limited to the more northern sections of the district, on the 9th–10th and the 28th. Timely warnings were issued for all of the cold waves, with livestock warnings where severe conditions were indicated.

On the 16th, the p. m. map showed a well-defined trough of low pressure extending eastward from the Pacific coast to the lower Missouri Valley and an area of high pressure, attended by severe cold, was advancing southward from western Canada. Cold-wave warnings were issued for Oklahoma and the Texas Panhandle. The next morning more intense conditions prevailed, with the depression central over southern Kansas, and

the warning was extended over the remaining interior sections. On local indications the official in charge at Galveston displayed northwest storm warnings at 4:30 p. m. At 8 p. m. of the 17th northwest storm warnings were ordered from Morgan City, La., to Brownsville, Tex., with extension of cold-wave warnings to the Texas coast and over southwestern Louisiana; and at 8:40 a. m. of the 18th storm and cold-wave warnings were issued for the remainder of the Louisiana coast. Gales occurred, as predicted, along the entire Texas coast, and there were destructive tornadoes in a few localities in northern Louisiana.

Small-craft warnings were displayed on the Texas coast on the 9th and 23d and were justified. Northeast storm warnings were ordered displayed on the Texas coast at 8:30 p. m. of the 27th, but the increase in wind velocity was gradual and not sufficient on the 28th to justify storm warnings.

Frost warnings were issued on the 20th for the coast sections of Louisiana and Texas, except for the Lower Rio Grande Valley, and on the 25th for northern Louisiana. Towards the close of the month, vegetation was sufficiently advanced in the eastern portion of the district for frost warnings as far north as Little Rock, Ark.

"Norther" warnings for Tampico, Mexico, were issued on the 9th and 18th.—*R. A. Dyke.*

DENVER FORECAST DISTRICT

Low pressures prevailed in Alaska, western Canada, and on the extreme north Pacific coast from the 1st to the 4th, attended by frequent snows in Montana, northwestern Wyoming, and northern Utah, with temperatures much above normal until the 5th. High pressures in the northwestern sections from the 5th to the 8th, together with a moderate depression that remained over the Southwest, were attended by snows from Montana southward to Colorado and by colder weather that had extended on the 8th to southeastern New Mexico. Low pressures continued in the southern portion of the district until the 14th, and a disturbance of marked intensity advanced from the north Pacific coast southeastward across Colorado during the period from the 13th to the 16th. Precipitation resulted in about all portions of the district from the 12th to the 17th, with the heaviest in western Colorado, northern New Mexico, Arizona and Utah. Severely low temperatures east of the Divide in Montana on the 16th, 17th and 18th accompanied the advance of a HIGH from Alberta. A LOW of marked intensity, from Alaska, that extended southeastward across the northern and eastern portions of the district from the 18th to the 23d was attended by snow or rain as far southward as Colorado and northern New Mexico. The last important storm of the month developed over the southern portion of the Rocky Mountain region on the 26th and advanced, with decreasing intensity, to southwestern Texas on the 28th. Precipitation resulted from Montana southward to northern Arizona and northern and eastern New Mexico.

Warning of a moderate cold wave in eastern Colorado, extreme eastern New Mexico, and southern Wyoming was issued on the morning of the 8th. The warning was fully verified. Warning of a moderate cold wave in northeastern Wyoming and east of the divide in Montana, which was also fully verified, was issued on the morning of the 12th. On the morning of the 14th warning was issued of a moderate cold wave east of the divide in Montana, and the warning was extended on the evening of the same day to include Wyoming. Verification was received in eastern Montana, but the warning failed of verification in Wyoming, owing to the development of a LOW over the southern portion of that State. On the morning of the 16th warning was issued of a severe cold wave immediately east of the divide in Montana and in northern Wyoming. The warnings were extended on the evening of the 16th to include all of Wyoming, and moderate cold-wave warnings were issued for eastern and central Colorado. Severe cold-wave warnings were issued on the morning of the 17th for eastern Colorado and moderate cold-wave warnings for that portion of New Mexico east of the mountains. The warnings were verified except in western Wyoming. Warning of a moderate cold wave in extreme western Colorado and southern Utah, issued on the morning of the 28th, was verified in southwestern Colorado and extreme southeastern Utah.

A cold wave without warning occurred in eastern Montana on the 8th, owing to the unexpected strengthening and slow movement of a HIGH over that region. The cold wave, for which warnings were issued on the 28th, extended to southeastern Colorado, for which section warnings had not been prepared.

Warning of heavy snows in southwestern Colorado, northeastern Arizona, and southern Utah was issued on the morning of the 12th, together with livestock warnings for those sections. Heavy snows continued in the region specified until the night of the 16th–17th.

Forecasts of strong winds in eastern Colorado and Wyoming were issued in the interests of aviation on the 1st, 2d, 3d, 15th, 16th, 18th, 19th, 20th, 21st, and 22d. These were generally verified.—*J. M. Sherier.*

SAN FRANCISCO FORECAST DISTRICT

At the beginning of February the pressure over the greater part of the northeast Pacific Ocean was quite low and the subpermanent high-pressure system normally found between California and Hawaii was considerably south of its usual position. Weather conditions over the far western portion of the continent above latitude 35° were much disturbed in consequence; rains were of frequent and general occurrence, and southerly gales prevalent along the north coast. Warnings for the latter, which had been displayed on the Oregon-Washington coast on January 31, were continued almost uninterruptedly, with occasional extensions to cover Puget Sound and the northern California coast, until the 5th, when the pressure rose over the ocean east of the 140th meridian, and several days of comparatively undisturbed weather intervened. Frost warnings, incident to this pressure rise, were issued from the 8th to the 11th, inclusive, for orchard areas in northern California.

Although the barometer was high during the latter period over the far western States and for some distance westward, a change of unusual significance was taking place in the pressure situation over the northeast Pacific Ocean as a whole, which resulted in conditions thereover which were without parallel since the charting of ocean pressures was begun at the San Francisco forecast center, with the possible exception of the period April 1–5, 1926, when a situation similar in type, if not in intensity and length of duration, prevailed. The characteristics peculiar to both these periods were as follows: (1) The development of an oceanic LOW in the south end of a trough overlying the middle Pacific Ocean, (2) the simultaneous development of a LOW over the southwestern United States, and (3) the gradual dissolution of the high-pressure ridge which lay between these two low-pressure sys-

tems extending from the Gulf of Alaska southward to low latitudes off our western coast. So obvious was the trend of conditions to the westward that no hesitation was felt in the issuance of the regular weekly weather outlook on Saturday, February 12, predicting general rains in the far western States with snows in the mountains for the entire week. The day following storm warnings were ordered along the California coast, and warnings were issued to power and transportation interests to prepare for a succession of disturbances accompanied by heavy snows in the Sierra. The situation was so unusual that conservatism was properly abandoned and emergency measures were advocated.

The initial disturbance reached the California coast on February 13 and wet weather prevailed over the greater part of the Pacific Slope from then until the 26th, when the weather cleared and became settled in California, although light rains continued in parts of the North Pacific States. Especially stormy weather prevailed in California from the 13th to the 17th. Warnings were required on some part of the coast during all of this time, and strong winds or gales occurred daily. Exceptionally strong gales occurred during the night of 15th–16th, when a maximum velocity of 76 miles, southeast, was recorded at Point Reyes. The most notable feature, however, of this period was the extraordinary rainfall in southern California, which was unequalled in amount for any similar period since the deluge of January, 1916. Precipitation totals ranged from 5 to 12 inches at a great many observation points, and in some cases even greater amounts were reported. Many bridges were carried away, numerous highways rendered impassable by washouts, and communications variously interrupted. The pressure situation over the adjacent ocean during this time is especially worthy of remark. It was noted above that the Pacific high-pressure system was considerably south of its normal position, with concomitant disturbed weather on the coast north of latitude 35° during the time that this condition prevailed. During the period just mentioned, or more specifically, from the 11th to the 26th, inclusive, this high pressure system was not only far south of its normal position, but for a part of the time, namely, that when the stormiest weather was prevailing in southern California, it disappeared from the area of observation, and there was literally no Pacific HIGH in evidence. The first indication of its reestablishment was on the morning of February 18, and so obvious were the symptoms that special advices were telegraphed to southern California Weather Bureau officials and issued to the press predicting that the period of persistent rainfall was about to terminate, a forecast which was fully verified for the central and southern parts of California, and especially designed to relieve the anxiety which was entertained over a possible continuation of the heavy rains in the extreme southern end of the State, where repairs and rehabilitation were in progress.

The return to higher pressures over the lower latitudes of the ocean was attended by the reappearance of disturbances in the higher latitudes and storm warnings were almost continuously required at north coast ports from the 17th to the 25th, inclusive.—*T. R. Reed.*

RIVERS AND FLOODS

By H. C. FRANKENFIELD

Atlantic drainage.—A period of rain from February 18 to 23 with local heavy falls on February 19 and 23 caused moderate floods in the basins of the James River of Virginia and in the rivers of the Carolinas. The floods were of short duration, the usual warnings were issued, and the damage was little or nothing. Property to the value of $35,000 was reported as having been saved by the warnings. The Santee River of South Carolina was still in flood at the close of the month and did not crest at Ferguson until March 2.

East Gulf drainage.—Heavy rains on February 11–12 over the drainage area of the Alabama River caused a rapid rise in all rivers of that district, that in the upper reaches of the Alabama River being accentuated by the closing of many of the gates at Lock No. 12 and Mitchell Dam on the Coosa River. From 8 a. m., February 13, to 8 a. m., February 14, the rise in the Coosa River at Wetumpka, Ala., was 37.6 feet, and that in the Alabama River at Montgomery, Ala., 23.4 feet. The floods, however, were moderate, and no losses were reported except of a few cattle that had strayed back to the river after having been driven out of the lowlands when warnings were received.

The same general conditions prevailed over the Black Warrior and lower Tombigbee drainage of Alabama, although in much more pronounced form below the mouth of the Black Warrior River. The crest stage at Demopolis, Ala., was 52.5 feet, 13.5 feet above the flood stage, at 5 p. m., February 22, but at Lock No. 10, Tuscaloosa, Ala., the highest stage was 0.3 foot below the flood stage of 46 feet. Impounding of water behind the dam at Lock No. 17, 25 miles above, probably prevented a further rise of 6 or 8 feet at Tuscaloosa, and of a foot or two more at Demopolis. Lowlands for a distance of 175 miles below Demopolis were inundated, but the losses were only about $10,000, as a greater flood had occurred during January and after that flood there was little property subject to damage left in the river bottoms. Property valued at $4,000 was saved by the warnings.

Floods in the Pascagoula and Pearl systems of Mississippi and Louisiana were also moderate as a rule. The weather had been dry for several months; otherwise the amount of rain that fell from February 12 to 14 and on February 18 and 19 would have produced a much greater flood. The Lower Pearl and West Pearl Rivers were still in flood at the close of the month. Loss and damage as reported was $65,900, while the reported value of property saved through the warnings was $40,700. The loss to farmers was negligible.

Ohio drainage.—The January floods in the Wabash and White Rivers of Indiana continued during the early days of February, an ice gorge in the Wabash below Covington, Ind., causing a stage at Covington of 24 feet, or 8 feet above the flood stage, on February 1. There was a slight additional swell caused by the rains of February 5, but nothing more, and no damage was reported except that given in the MONTHLY WEATHER REVIEW for January, 1927.

The Green River of Kentucky was generally in flood from about January 22, and it was not until February 10 that the flood waters subsided over the lower reaches. The crest stages were from 12 to 14 feet above the flood stages, with a maximum at Lock No. 4, Woodbury, Ky. Warnings were widely distributed before and during the high water, and the total of reported losses was small. The American Red Cross contributed effectively to relief work along the middle reaches of Green River.

Heavy rains over the upper Tennessee River drainage on February 22 and 23 caused a decided rise in all upper tributaries and the upper river, with moderate flood stages in several of the former and at Rockwood, Tenn., on the latter. No damage was reported. At the end of

the month the crest of this rise had just reached Guntersville, Ala.

Ohio River.—The Ohio River passed below the flood stage of 28 feet at Louisville, Ky., on February 1, and at Cloverport, Ky., during February 4, but not until 10:30 p. m., February 9, at Evansville, Ind., and during the night of February 14 at Cairo, Ill. At Evansville a crest of 44.8 feet was reached on January 30, and at Cairo a crest of 48.9 feet on February 6 and 7. These latter dates marked the end of the flood that began at Pittsburgh, Pa., on January 21. During this flood the Cumberland and Tennessee Rivers were not in flood, but the Ohio above the mouth of the Cumberland was much higher than in late December and early January. The upper Mississippi was also low.

This flood did not differ much from other great Ohio River floods, except in the remarkable smallness of the loss and damage. In the Evansville district, direct Ohio River losses were $69,940, and in the Cairo district, $48,950, of which $39,250 was in crops, mostly in the State of Kentucky. Reported savings through flood warnings were between $50,000 and $100,000 in the Evansville district and $77,000 in the Cairo district. About 23,000 acres of land were overflowed in Illinois and 15,000 acres in Kentucky.

Lower Mississippi River.—The flood in the lower Mississippi River was virtually continuous throughout the month. The river at New Madrid, Mo., reached the flood stage of 34 feet on February 1, a crest of 37.6 feet on February 8, and had fallen only to 29.3 feet on February 26, when another and greater rise set in. Report on this flood must be further delayed, as the river did not reach the flood stage of 17 feet at New Orleans until February 13, and was still rising at the end of the month. The Yazoo River of Mississippi remained high throughout the month, and the Atchafalaya and Ouachita Rivers of Louisiana moderately so.

Illinois River.—Heavy rains and melting snows around February 4 and 5 caused another marked flood in the Illinois River with crests from 4.5 to about 8 feet above the flood stages. A full river when the rains began and a low Mississippi River balanced one another and the rise was about normal for the amount of rain and melted snow. Warnings were issued for 10 days, and below Peoria the river was still in flood at the close of the month.

White and Black Rivers of Arkansas.—The floods in these rivers began about January 22 and were due to a series of heavy rains from January 19 to 26. While the floods were not severe, several thousand acres of farm land were overflowed in the territory back of White River Levee and about 1,000 residents were driven from their homes for two weeks or more. The levee broke in a few places, but the greater portion stood. Most of the stock and portable property had been removed as soon as the first warnings were received. The lower St. Francis River of Arkansas was also somewhat above flood stage during the greater portion of the month, as was also the Arkansas River near its mouth, mainly on account of the flood in the Mississippi River.

Colorado River and tributaries.—Precipitation from February 11 to 17 was heavy at times over northern and central Arizona and rises unusual for the season occurred in the lower Colorado and the Gila Rivers. While flood stages were not reached in the Colorado, the situation was such as to necessitate warnings. River conditions in the lower valley were precarious, the people were much alarmed, and the warnings proved of great value. There was no damage. In the Gila and Salt and other tributary streams flood conditions prevailed, with a crest of 10 feet, 5 feet above the flood stage, in the Salt River at Phoenix, Ariz., on February 17. Warnings were issued for the lower districts, but little could be done to protect crops. Losses reported were $11,800. The heaviest rains occurred over a limited area in the central portion of the State, and at Prescott the rainfall was the greatest recorded in any one month since 1866.

Pacific drainage—Sacramento system.—Five days of excessive rains within a week over the upper drainage of the Sacramento River of California could have but one sequence, and the only question was of the intensity of the flood. At Kennett, the total rainfall from February 14 to 20, inclusive, was 13.15 inches, of which all but 0.45 inch fell in five days which, however, were not consecutive. At Red Bluff, 73 miles below Kennett, the rainfall during the same period was 4.44 inches, and somewhat less farther south. There were also heavy rains over the tributary mountain drainage to the eastward.

By February 18 it was apparent that a flood was imminent, and warnings were issued for the Sacramento and for the mountain tributaries. Late afternoon reports on February 20 indicated that heavy rains were falling upon the snows over the high altitudes to the north and on the soft snow in the Sacramento Canyon, and additional warnings were issued at once. The heavy rains continued to fall, and on the morning of February 21 general warnings were issued for the Sacramento River as far south as the mouth of the American River. Thirty gates of the Sacramento Weir were opened during the day, permitting a vast quantity of water to flow into Yolo Basin, and at the same time Fremont Weir, near the mouth of Feather River, was discharging into the basin large volumes of excess water from the Feather-Yuba and Bear Rivers. Then began a spectacular fight by the farmers below to save their lands. Their efforts were only partially successful, and within two days, more than 15,000 acres of lands had been flooded. One large tract of 6,000 acres was protected by sandbags on top of a 4-mile levee, and the water crested within four inches of the top of the double line of bags. A break in the levee two miles above Colusa on the Sacramento River was the only break reported, and several thousand acres of orchards were overflowed.

Warnings were frequently issued and they covered all sections affected. At Sacramento the situation was much relieved by the opening of the gates of the weir. Reports of losses were very incomplete, but those reported aggregated $275,000, of which $60,000 was in crops. The value of property saved through the warnings was given as $135,000. Many expressions of commendation for the service rendered by the Weather Bureau were received, and among them letters from the managers of the reclamation and levee districts, who were enabled to combat successfully with the flood waters.

Willamette system.—There were two floods in the system. The first, during the early days of the month, was unimportant, but the second was more pronounced and caused much damage.

The second flood was caused by the same series of general and heavy rains that caused floods in California. In Oregon the season had been unusually wet, and when the rains began on February 15 they fell upon soil well saturated, with deep snow in the mountains and some snow in the foothills. The heaviest rains fell on Feb-

ruary 19 and 20, and on the morning of the latter date the first warnings were issued for the Santiam River and a few hours later for the Willamette and tributaries as far down as Eugene, Oreg. On February 21 warnings covered the lower river, with 18 feet, or 3 feet above flood stage, forecast for Portland. The actual crest was 18.1 feet on February 24. The breaking of a dyke in the Santiam River, 1 mile above Jefferson, Oreg., probably lowered the crest at Jefferson about 1 foot. There were also floods at the same time in the Rogue and Umpqua Rivers of southern Oregon, as well as in smaller streams. No service is maintained on these rivers.

Losses of $386,505 were reported, not including losses due to suspension of business. The reported value of property saved by the warnings was $161,000. Information as to the latter item was, as usual, very incomplete. Expressions of appreciation for the service rendered were numerous.

River and station	Flood stage	Above flood stages (dates) From—	Above flood stages (dates) To—	Crest Stage	Crest Date
ATLANTIC DRAINAGE					
James:	*Feet*			*Feet*	
Columbia, Va.	18	Feb. 20	Feb. 21	21.0	Feb. 20
Richmond, Va.	10	21	21	10.0	21
Roanoke:					
Randolph, Va.	21	21	21	23.3	21
Weldon, N. C.	30	21	23	36.6	22
Peedee:					
Cheraw, S. C.	27	25	25	27.0	25
Mars Bluff, S. C.	17	27	(1)	17.5	28
Santee:					
Rimini, S. C.	12	23	(1)	13.6	28
Ferguson, S. C.	12	25	(1)	12.8	28
Broad: Blairs, S. C.	15	24	26	15.4	24
Saluda:					
Pelzer, S. C.	7	24	24	8.4	24
Chappells, S. C.	14	20	20	[2] 14.7	20
EAST GULF DRAINAGE					
Alabama: Selma, Ala.	35	16	21	37.8	17
Etowah: Canton, Ga.	11	14	14	13.9	14
Cahaba: Centerville, Ala.	25	14	14	27.0	14
Tombigbee: Lock No. 4, Demopolis, Ala.	39	14	Mar. 1	52.5	22–23
Pascagoula: Merrill, Miss.	20	17	Feb. 24	21.2	20
Chickasawhay:					
Enterprise, Miss.	21	15	15	21.6	15
Shubuta, Miss.	27	14	22	30.1	19
Leaf: Hattiesburg, Miss.	19	14	16	20.0	15
Pearl:					
Edinburgh, Miss.	21	19	22	22.0	21
Jackson, Miss.	20	16	(1)	30.0	23–24
Monticello, Miss.	18	14	16	19.6	15
Columbia, Miss.	18	14	28	21.2	16
Bogue Chitto: Franklinton, La.	16	14	15	17.3	14
West Pearl: Pearl River, La.	13	16	(1)	16.4	18
GREAT LAKES DRAINAGE					
St. Joseph: Montpelier, Ohio	10		9	10.8	8
MISSISSIPPI DRAINAGE					
Ohio:					
Louisville, Ky.	28	(2)	1	35.6	Jan. 27
Dam 41, Ky.	51	(2)	1	58.7	27
Dam No. 44, Leavenworth, Ind.	48	(2)	3	60.1	27
Cloverport, Ky.	40	(2)	4	49.1	28
Evansville, Ind.	35	(2)	9	44.8	29–30
		Feb. 26	Mar. 6	37.3	Mar. 2
Dam No. 48, Cypress, Ind.	35	(2)	9	44.7	Jan. 31
Mount Vernon, Ind.	35	(2)	11	45.4	Jan. 31–Feb. 1
Shawneetown, Ill.	35	(2)	15	47.9	Feb. 2
Paducah, Ky.	43	3	9	44.2	6
Cairo, Ill.	45	1	13	48.9	7
		6	7	9.4	7
Tuscarawas: Gnadenhutten, Ohio	9	24	28	10.2	26
Scioto: Larue, Ohio	11	6	6	11.1	6
Green:					
Lock No. 4, Woodbury, Ky.	33	(2)	1	46.8	Jan. 25
Lock No. 2, Rumsey, Ky.	34	(2)	12	43.2	Feb. 1–2
Wabash:					
Lafayette, Ind.	11	(2)	10	21.9	Jan. 31
Covington, Ind.	16	(2)	11	[4] 24.0	Feb. 1
Terre Haute, Ind.	16	3	12	18.6	6
Vincennes, Ind.	14	7	17	16.8	11
Mount Carmel, Ill.	16	(2)	18	19.6	2
		(2)	6	6.4	1–2
Tippecanoe: Norway, Ind.	6	9	12	6.4	10
		14	24	6.4	15–16
White: Decker, Ind.	18	(2)	3	22.3	Jan. 28
White, West Fork:					
Elliston, Ind.	19	2	4	20.0	Feb. 2–3
		7	8	19.3	7
Edwardsport, Ind.	15	1	11	17.3	4

[1] Continued at end of month.
[2] Estimated.
[3] Continued from last month.
[4] Ice gorge below station.

River and station	Flood stage	Above flood stages (dates) From—	Above flood stages (dates) To—	Crest Stage	Crest Date
MISSISSIPPI DRAINAGE—continued					
Tennessee:	*Feet*			*Feet*	
Rockwood, Tenn.	20	25	26	21.2	25
Widows Bar Dam, Ala.	26	25	(1)	29.7	27
French Broad: Dandridge, Tenn.	12	24	24	13.0	24
Big Pigeon: Newport, Tenn.	6	23	23	8.4	23
Holston: Rogersville, Tenn.	14	24	24	19.0	24
Holston, North Fork: Mendota, Va.	8	23	24	10.1	24
Clinch: Clinton, Tenn.	25	25	25	25.4	25
Mississippi:					
New Madrid, Mo.	34	1	16	37.6	8
Memphis, Tenn.	35	5	20	37.8	12–13
Helena, Ark.	44	7	24	47.3	15
Arkansas City, Ark.	48	6	28	51.8	17–19
Greenville, Miss.	42	8	28	44.8	17–20
Vicksburg, Miss.	45	6	(1)	49.5	21–24
Natchez, Miss.	46	12	(1)	49.5	23–27
Angola, La.	45	13	(1)	48.1	25–28
Baton Rouge, La.	35	12	(1)	39.0	[3] 28
Donaldsonville, La.	28	12	(1)	30.9	[3] 26–28
New Orleans, La.	17	13	(1)	18.5	[3] 25–28
Illinois:					
Morris, Ill.	13	8	11	20.0	6
Peru, Ill.	14	1	(1)	22.1	7
Henry, Ill.	10	4	(1)	16.1	9
Peoria, Ill.	18	5	27	22.6	10
Havana, Ill.	14	4	(1)	18.3	14
Beardstown, Ill.	14	4	(1)	20.0	15
Pearl, Ill.	12	5	(1)	16.2	16
St. Francis: Marked Tree, Ark.	17	1	20	18.6	7–11
Arkansas: Yancopin, Ark.	29	(2)	(1)	38.2	15–19
White:					
Newport, Ark.	26	(2)	4	32.6	Jan. 26
Georgetown, Ark.	22	(2)	14	28.9	30
Clarendon, Ark.	30	(2)	13	32.6	Feb. 4–5
Black:					
Corning, Ark.	11	(2)	16	15.0	Jan. 26–28
Black Rock, Ark.	14	(2)	14	26.3	23
Cache: Patterson, Ark.	9	(2)	15	11.2	Feb. 6–7
Yazoo: Yazoo City, Miss.	25	(2)	(1)	30.4	Jan. 21
Tallahatchie: Swan Lake, Miss.	25	(2)	28	31.1	7–9
Sulphur: Finley, Tex.	24	(2)	1	24.4	Jan. 31
Ouachita: Camden, Ark.	30	Jan. 25	2	33.8	Jan. 29
Atchafalaya: Melville, La.	37	Feb. 14	(1)	39.0	Feb. 28
Little: Little River, Tex.	30	9	10	35.5	Feb. 10
PACIFIC DRAINAGE					
Gila:					
Kelvin, Ariz.	5	15	16	6.8	15
Gila Bend, Ariz.	5	17	18	5.7	18
Salt: Phoenix, Ariz.	5	16	18	10.0	17
Sacramento:					
Red Bluff, Calif.	23	21	21	20.5	21
Knights Landing, Calif.	18	18	26	19.8	22
Yuba: Colgate, Calif.	14	21	21	14.2	21
Willamette:					
Eugene, Oreg.	12	20	22	17.0	21
Albany, Oreg.	20	21	24	20.2	22
Salem, Oreg.	20	22	24	24.9	23
Oregon City, Oreg.	12	22	26	15.6	24
Portland, Oreg.	15	23	26	18.1	24
Willamette, Coast Fork: Saginaw, Oreg.	9	20	22	12.2	21
Willamette, Middle Fork: Eula, Oreg.	13	21	21	17.0	21
Santiam: Jefferson, Oreg.	10	2	2	10.3	2
		21	21	16.0	21
North Santiam: Mehama, Oreg.	15	21	21	15.0	21

[1] Continued at end of month.
[3] Continued from last month.

MEAN LAKE LEVELS DURING FEBRUARY, 1927

BY UNITED STATES LAKE SURVEY

[Detroit, Mich., March 4, 1927]

The following data are reported in the Notice to Mariners of the above date:

Data	Lakes [1] Superior	Michigan and Huron	Erie	Ontario
Mean level during February, 1927:	*Feet*	*Feet*	*Feet*	*Feet*
Above mean sea level at New York	601.32	578.25	570.97	245.31
Above or below—				
Mean stage of January, 1927	−0.12	+0.06	−0.16	+0.03
Mean stage of February, 1926	+1.08	+0.83	+1.07	+1.21
Average stage for February, last 10 years	−0.19	−1.15	−0.19	+0.31
Highest recorded February stage	−1.16	−4.47	−2.78	−2.36
Lowest recorded February stage	+1.08	+0.83	+1.07	+1.48
Average departure (since 1860) of the February level from the January level	−0.20	+0.03	−0.08	+0.07

[1] Lake St. Clair's level: In February, 1927, 572.40 feet.

EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, FEBRUARY, 1927

By J. B. KINCER

General summary.—The weather during the first part of the month was characterized by uniformly mild conditions for the season in nearly all sections of the country. About the beginning of the second week, however, an extensive high-pressure area, accompanied by much colder weather, overspread the Northwestern States and drifted southward over the southern Great Plains and the Southeast. The cold moderated considerably before reaching the latter section, although there was a sharp fall in temperature over the Southwest with freezing extending well southward over Texas. Storms were rather active during the third week with low pressure areas causing widespread rain over southern districts and rain or snow over most Central and Northern States east of the Mississippi River. During the last week there was a return to generally pleasant weather in nearly all portions of the country and temperatures were well above normal in most areas.

The mild, open, and mostly fair weather during the first part made conditions favorable for outside work and greatly reduced the snow cover that was present at the beginning of the month. The moderate to substantial rains in the Southeast were very beneficial in conditioning the soil, and abnormal development of all vegetation was noted. The continued warm weather had advanced fruit too rapidly, with the earlier varieties blooming quite generally throughout the Gulf section during the second week. Fruit trees continued to advance prematurely during the latter part of the month and at the close some early varieties were in bloom as far north as central Arkansas. While there was some interruption to farm work in the Southeast by rain, the additional moisture was beneficial; in some southwestern areas the soil continued too wet to work. Toward the close of the month conditions became more favorable for work in the Southwest, with seasonal operations advancing satisfactorily.

Small grains.—There was practically no snow cover in the principal wheat-producing sections at the beginning of the month, but beneficial precipitation occurred during the second week, the generous snowfall over the northwestern portion being especially helpful. Some complaint of freezing and thawing was made in northern areas, but this was not widespread, and the wheat crop continued in generally fair to good condition in most sections. During the last half of the month wheat was reported greening up in the lower Missouri Valley and furnishing some pasturage in Kansas. Cereal crops in Southern States continued in mostly good condition with the moisture in the Southeast of considerable benefit. There was some complaint of green bugs appearing locally in the Southwest.

Ranges, pastures, and livestock.—Pastures showed improvement in the Southeast under improved moisture conditions and favorable temperatures. The absence of storms during the first week was beneficial for livestock in the great western grazing areas, while the open conditions in the northern Great Plains permitted free ranging. The weather was less favorable during the second week, but rain or snow in the far Southwest augmented water supplies and improved the desert range. Generous precipitation over southwestern sections during the latter part was beneficial for the range and further increased the water supply. Livestock continued in mostly satisfactory condition, with lambing making good advance in the West at the close.

Miscellaneous crops.—Progress and condition of truck crops in winter-producing areas was almost continuously good throughout the month. Potato planting advanced rapidly in most areas of the Southeast, with planting beginning in southern Arkansas at the close.

The unseasonably mild weather during February caused premature swelling of fruit buds and at its close peaches, pears, and plums were in bloom as far north as central Arkansas and peach buds were showing color in the southern Ohio Valley. Citrus were making new growth in Florida and leafing and much bloom was noted in some districts. Good conditions for citrus prevailed in California the first part, but later the continued damp weather caused some rotting of navels on the trees.

WEATHER ON THE ATLANTIC AND PACIFIC OCEANS

NORTH ATLANTIC OCEAN

By F. A. YOUNG

Taking the ocean as a whole, the weather over the North Atlantic during February presented few unusual features, although in the region between the 45th and 50th parallels and the 30th and 45th meridians gales were reported on from eight to nine days, which is considerably above the normal as shown on the Pilot Chart. In a number of squares in the middle and eastern sections of the ocean gales occurred on from five to seven days, and several ships encountered winds of force 11 and 12, as shown in table.

The number of days with fog was considerably below normal over the Grand Banks and in the middle section of the steamer lanes; it was unusually prevalent, however, in the square between the 35th and 40th parallels and the 70th and 75th meridians, where it was observed on 13 days. Fog also occurred on four to six days over the eastern section of the steamer lanes and in the North Sea, and on three days in the Gulf of Mexico.

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level, 8 a. m. (75th meridian), North Atlantic Ocean, February, 1927*

Stations	Average pressure	Departure [1]	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Julianehaab, Greenland	[2] 29.33	([3])	29.78	17th	28.91	1st.[4]
Belle Isle, Newfoundland	[5] 29.82	+0.07	30.58	20th	29.16	3d.
Halifax	30.01	+0.03	30.74	20th	29.28	4th.
Nantucket	29.99	−0.07	30.36	1st	29.46	26th.
Hatteras	30.06	−0.07	30.52	1st	29.72	19th.[4]
Key West	30.10	+0.02	30.24	2d [4]	29.72	19th.
New Orleans	30.08	−0.02	30.28	1st [4]	29.70	18th.
Swan Island	29.96	−0.03	30.02	16th	29.82	19th.
Turks Island	30.15	+0.07	30.24	13th	30.06	19th.
Bermuda	30.19	+0.05	30.36	2d	29.98	26th.[4]
Horta, Azores	30.10	−0.03	30.36	1st [4]	29.72	24th.
Lerwick, Shetland Islands	29.88	+0.16	30.55	9th	29.08	23d.
Valencia, Ireland	29.92	+0.02	30.59	6th	28.74	22d.
London	30.07	+0.07	30.58	14th [4]	29.20	24th.

[1] From normals shown on H. O. Pilot Chart based on observations at Greenwich mean noon, or 7 a. m., 75th meridian.
[2] Mean of 21 observations; seven days missing.
[3] No normal established.
[4] And on other dates.
[5] Mean of 24 observations; four days missing.

The month began with a disturbance over Newfoundland that moved rapidly eastward and on the 3d was apparently in the vicinity of the south coast of Iceland.

Charts VIII to XI cover the period from the 3d to 6th, inclusive, when extremely stormy conditions prevailed over a large portion of the ocean.

On the 8th a well-developed LOW was central near 50° N., 42° W., and gales of force 8 to 12 prevailed between the 40th and 50th parallels and the 30th and 45th meridians. This LOW moved rapidly northeastward, decreasing in intensity, and on the 9th and 10th moderate weather was the rule over nearly the entire ocean, although on the 9th the station at Horta reported a southerly wind, force 8, with rain.

From the 11th to 13th, inclusive, a depression accompanied by moderate to strong gales was over the region between the Azores and 50th parallel and the 20th and 45th meridians.

On the 14th and 15th reports of winds of force 7 to 9 were received from vessels in various parts of the ocean, while over large areas moderate weather prevailed.

From the 16th to 18th a slow-moving disturbance covered the middle section of the steamer lanes, the storm area extending from the 35th to 50th parallels and the 30th to 60th meridians. On the 18th there was also a well-defined LOW over the western part of the Gulf of Mexico which moved rapidly northeastward along the coast, and on the 19th was central near Savannah. On both dates westerly to northwesterly winds of force 7 to 9 occurred in the Gulf, which is unusual, as cyclonic winds of gale force are rare in this region during the winter.

On the 20th an area of high pressure was over the province of Quebec, with its crest near Father Point, where a barometric reading of 30.94 inches was recorded. On the same day a LOW was centered over Chesapeake Bay, and the stations at Nantucket and Atlantic City both reported northeast wind, force 10, accompanied by snow.

On the 21st and 22d the eastern section of the steamer lanes was covered by a deep depression, and northwesterly gales of force 8 to 11 were encountered east of the 40th meridian.

From the 23d to 25th there was considerable cyclonic activity over the middle section of the ocean, and on the 23d and 24th northerly to northeasterly gales were encountered between the 20th meridian and coast of Scotland.

From the 26th to 28th there ensued another period of heavy weather in the eastern section, the storm area on the 26th and 27th extending as far west as the 40th meridian, while on the 28th it was restricted to the region between the 45th and 50th parallels and the 0 and 20th meridians, west longitude. On the 26th Nantucket was near the center of a LOW that moved rapidly eastward, and on the 27th was near 43° N., 52° W. On both dates southerly gales were encountered in the easterly quadrants.

NOTE.—Capt. David Pearson of the American Steamship *Sudawsonco*, has furnished the following note regarding meteorological phenomena observed by him on February 15, 1927, in latitude 45° 25′ N. and longitude 35° 30′ W.:

> I observed three whirlwinds within a radius of 10 miles; two were close together, while the third was northwest about 4 miles. The two that were close together were within 1½ miles of the ship. They were revolving from left to right and working their way from the southward to windward almost in the face of a northwest gale of force 9. The progressive speed of the whirlwinds I should judge was about 8 miles per hour and the vortices anything up to hurricane force, at times almost forming a waterspout. Our barometer read at the time 29.60 inches.

OCEAN GALES AND STORMS FEBRUARY, 1927

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH ATLANTIC OCEAN			° ′	° ′				*Inches*					
Maine, Dan. S. S.	Baltimore	Bremen	38 12 N.	62 46 W.	Feb. 2	2 p., 2	Feb. 3	29.80	SW	W., —	NW	WNW., 10	SW.-NW.
München, Ger. S. S.	New York	Queenstown	48 48 N.	31 12 W.	3	Mdt. 3	5	29.43	SSW	SSW., 11	W	SW., 12	SSW.-S.-SW.
Nevada, Dan. S. S.	do	Copenhagen	58 48 N.	14 13 W.	3	6 a., 3	3	29.02	WSW	WSW., 10	WNW	—, 10	WSW.-WNW.
Pres. Harding, Am. S. S.	Queenstown	New York	46 36 N.	46 32 W.	1	8 a., 3	6	28.72	SW	SW., 11	NW	W., 12	SW-NW.
Mijdrecht, Du. S. S.	Seville	do	37 20 N.	67 25 W.	2	1 a., 4	4	29.62	SSW	SSW., 10	N	NW., 12	SSW.-NW.
Housatonic, Br. S. S.	Baytown, Tex.	London	34 43 N.	55 27 W.	4	6 p., 4	6	29.60	SW	WSW., 8	NW	WSW., 9	SW.-WSW.
Oxonian, Br. S. S.	Glasgow	Louisburg, N. S.	51 00 N.	37 00 W.	4	2 a., 4	4	28.83	SSE	SW., 12	SW	SW., 12	SE.-SW.
Do	do	do	50 30 N.	40 00 W.	5	9 a., 5	6	28.56	S	SE., 10	NW	SW., 12	SE.-SW.
West Celina, Am. S. S.	Norfolk	Bremen	41 35 N.	32 50 W.	6	Noon, 6	6	30.00	S	S., 10	NW	S., 10	S.-NW.
Missouri, Br. S. S.	Plymouth	New York	46 50 N.	37 00 W.	7	6 p., 7	8	29.92	S	S., 10	W	S., 10	S.-SW.
Housatonic, Br. S. S.	Baytown	London	41 17 N.	41 12 W.	7	11 a., 8	8	29.65	S	S., 10	WNW	S., 10	S.-WNW.
Illinois, Am. S. S.	Port Arthur	Stockholm	41 54 N.	44 56 W.	7	4 a., 8	8	29.40	SW	NW., 10	NW	NW., 11	SW.-N.-W.
Tomalva, Am. S. S.	Antwerp	New York	46 31 N.	34 42 W.	8	—, 8	8	29.55	SSW	S., 9	W	SSW., 10	S.-W.
West Madaket, Am. S. S.	Liverpool	Mobile	39 00 N.	29 40 W.	10	9 p., 10	11	29.71	SW	SW., —	WNW	WNW., 9	SW.-WNW.
Sacandaga, Am. S. S.	New York	Antwerp	47 10 N.	34 38 W.	11	5 p., 11	12	29.62	SSW	SSW., 10	W	W., 11	SSW.-W.
Iowa, Fr. S. S.	Havre	Fort de France.	44 20 N.	22 11 W.	11	5 p., 11	11	29.62	NNW	NNW., 10	NW	NNW., 10	Steady.
St. Andrew, Br. S. S.	Galveston	Bremen	42 40 N.	41 55 W.	12	3 a., 13	13	29.16		N., —	WNW	N., 10	E.-N.-WNW.
Nieuw Amsterdam, Du. S. S.	Rotterdam	Halifax	47 46 N.	24 28 W.	13	6 p., 13	14	28.76	ESE	SSW., 6	WNW	NW., 10	ESE.-S.-NW.
Stockholm, Swed. S. S.	Gothenburg	New York	55 30 N.	29 42 W.	14	8 a., 15	15	29.27	SSE	SSW., 9	WSW	SW., 10	SSE.-WSW.
Maine, Br. S. S.	Antwerp	do	43 35 N.	49 01 W.	16	11 p., 16	17	29.11	NNW	NNW., —	NNW	NW., 10	
Stockholm, Swed. S. S.	Gothenburg	do	49 12 N.	43 00 W.	17	4 p., 17	18	29.30	ENE	NNE., 10	NW	N., 11	ENE.-N.-NW.
Gulfking, Am. S. S.	Savannah	Port Arthur	27 45 N.	89 00 W.	18	10 p., 18	19	29.60	N	—, 8	N	—, 9	
E. J. Sadler, Am. S. S.	Balboa	New York	22 00 N.	84 00 W.	19	2 a., 19	19	29.86	SW	SW., 7		W., 9	W.-WNW.
Sinsinawa, Am. S. S.	Gibraltar	do	38 35 N.	72 20 W.	19	7 a., 19		29.84	Var	NE., 5		NE., 10	Steady.
Minnekahda, Am. S. S.	New York	London	39 56 N.	70 38 W.	19	Mdt. 20	20	29.94	NE	ENE., 8	ENE	ENE., 10	Do.
München, Ger. S. S.	Queenstown	New York	48 19 N.	34 18 W.	20	8 p., 20	21	29.48	NW	NW., 6	WNW	NW., 11	
Mascanamo, Ger. S. S.	Houston	Land's End	43 35 N.	32 00 W.	20	6 a., 21	22	29.57	W	NW., 11	W	NW., 11	
West Hardaway, Am. S. S.	London	Pensacola	45 26 N.	18 26 W.	21	3 p., 21	22	29.02	SW	NW., —	W	NNW., 12	SW.-NW.
Sac City, Am. S. S.	Antwerp	New York	49 12 N.	14 35 W.	21	Mdt. 21	27	28.86	S	NW., 9	NW	NNW., 12	SSW.-NW.
Emanuel Nobel, Belg. S. S.	London	New Orleans	43 00 N.	22 30 W.	23	8 p., 23	26	29.34	W	SW., 8	SW	W., 10	SW.-WSW.
Bloomfield, Br. S. S.	Rouen	Baton Rouge	43 07 N.	22 48 W.	25	6 p., 25	27	29.71	SW	SW., —	NW	—, 11	SW.-NW.
Am. Banker, Am. S. S.	New York	London	40 46 N.	64 10 W.	26	4 p., 26	27	29.24	SE	SE., 10	W	SE., 10	S.-SW.-W.
Mascanamo, Ger. S. S.	Houston	Land's End	48 44 N.	11 55 W.	26	9 a., 26	27	28.48	S	SW., 10	W	W., 12	S.-SW.-W.
Japanese Prince, Br. S. S.	Suez	New York	40 03 N.	29 31 W.	23	11 p., 26	Mar. 1	28.87	SW	SW., 12	WNW	SW., 12	SW.-W.-NW.
Westland, Am. S. S.	Manchester	Mobile	45 10 N.	15 38 W.	27	4 p., 27	Feb. 28	28.82	SW	—, 12	N	—, 11	W.-NW.
Innoko, Am. S. S.	Rotterdam	New York	49 53 N.	5 00 W.	27	Noon, 28	Mar. 1	28.94	SSW	SW., 9	WNW	SW., 10	SW.-WSW.

Ocean gales and storms, February, 1927—Continued

Vessel	Voyage		Position at time of lowest barometer		Gale began	Time of lowest barometer	Gale ended	Lowest barometer	Direction of wind when gale began	Direction and force of wind at time of lowest barometer	Direction of wind when gale ended	Highest force of wind and direction	Shifts of wind near time of lowest barometer
	From—	To—	Latitude	Longitude									
NORTH PACIFIC OCEAN			° ′	° ′				*Inches*					
Las Vegas, Am. S. S.	Pacific coast	Yokohama	51, 11 N.	170 30 W.	Jan. 30	4a., 30	Feb. 2	28.69	W	SW., —	WSW	—, 9	SSW.-WSW.
Pawlet, Am. S. S.	Manila	San Francisco.	42 00 N.	138 00 W.	Feb. 1	2a., 2	2	29.18	SSE	S., 11	W	S., 11	4 pts.
Waitemata, Br. S. S.	Westport, N. Z.	Vancouver	39 00N.	135 54 W.	1	4a., 2	3	29.15	S	S., 8	W	W., 9	S.-WNW.
Grootendijk, Du. S. S.	Portland	San Francisco.	42 19 N.	124 44 W.	1	8p., 2	3	29.58	SSW	SSE., 9	SW	SSE., 9	S.-SSE.
Kaisho Maru, Jap. S. S.	Muroran	William Head, B. C.	49 41 N.	132 49 W.	1	3a., 1	3	28.83	NE	NW., 5	S	S., 9	
Makiki, Am. S. S.	Seattle	Honolulu	39 32 N.	138 47 W.	2	1a., 2	2	28.00	SW	W., 9	W	W., 9	SW.-W.
Steel Exporter, Am. S. S.	San Francisco.	do	34 20 N.	133 20 W.	4	5a., 5	5	29.62	S	S., 7	NNW	S., 8	
Pres. Jefferson, Am. S. S.	Seattle	Yokohama	52 00 N.	167 10 W.	5	2a., 6	6	28.58	E	N., 9	NNW	N., 9	E.-NE.-N.
West Carmona, Am. S. S.	Hongkong	San Francisco.	38 07 N.	172 27 E.	5	12 M., 5	6	29.67	W	WNW., 7	WNW	WNW., 9	Steady.
Dilworth, Am. S. S.	Cebu, P. I.	Portland	50 40 N.	152 00 W.	5	6p., 5	6	28.95	ESE	SE., 9	SSW	SE., 9	ESE.-SE.
West Prospect, Am. S. S.	San Francisco.	Yokohama	31 30 N.	159 40 E.	6	6p., 6	7	29.57	SW	SW., 8	W	W., 11	SW.-W.
Bengal Maru, Jap. S. S.	Yokohama	San Francisco.	36 30 N.	157 45 E.	6	11p., 7	8	28.90	SE	W., 9	NW	NW., 10	W.-NW.
West Carmona, Am. S. S.	Hongkong	do	37 50 N.	175 12 W.	7	11a., 7	7	28.93	NW	W., 2	N	N., 9	W.-NW.
H. T. Harper, Am. S. S.	Richmond, Calif.	Honolulu	28 47 N.	146 00 W.	8	5a., 10	10	29.68	SE	SSE.—	NW	SSE., 12	SSE.-WNW.
Emp. of Canada, Br. S. S.	Yokohama	Vancouver	50 57 N.	155 04 W.	8	8a., 10	11	29.12	SE	SE., 7	S	E., 9	SE.-ESE.
Pres. Wilson, Am. S. S.	Honolulu	Kobe	29 00 N.	176 23 W.	8	3p., 9	12	29.75	SW	WNW., 10	W	WNW., 10	W.-NW.
Kiyo Maru, Jap. S. S.	Yokohama	San Pedro	40 01 N.	159 00 W.	10	2a., 10	10	28.17		W., 7		—, 10	W.-WSW.
Koyu Maru, Jap. S. S.	Miike	Grays Harbor.	50 35 N.	154 35 W.	10	Noon, 11	13	28.04	E	ESE., 8	SE	ESE., 9	
Frank G. Drum, Am. S. S.	Gaviota	Honolulu	25 22 N.	148 57 W.	10	6a., 10	12	29.72	SSE	SW., —	NW	NW., 10	SW.-NW.
Robin Adair, Am. S. S.	San Francisco.	do	34 20 N.	131 45 W.	12	6p., 13	17	29.29	SSE	SW., 10	SW	SW., 10	S.-SW.
Kongosan Maru, Jap. S. S.	Yokohama	San Francisco.	38 45 N.	154 45 E.	14	4p., 14	15	29.76	W	WNW., 10	NW	WNW., 11	W.-WNW.
Do	do	do	42 00 N.	165 30 E.	16	8a., 17	17	29.32	E	ENE., 10	ENE	ENE., 10	E.-ENE.
Manukai, Am. S. S.	Honolulu	do	32 40 N.	134 30 W.	15	Noon, 15	15	29.39	S	S., 8	S	S., 8	Steady.
Memphis City, Am. S. S.	San Pedro	Yokohama	30 57 N.	133 00 W.	13	1p., 13	17	29.60	W	W., —	WNW	W., 10	
Canad. Seigneur, Br. S. S.	Vancouver	Balboa	37 05 N.	123 12 W.	15	Mid., 15	16	29.48	SE	SE., 7	S	SSW., 8	SE.-SSW.
Pres. Wilson, Am. S. S.	Honolulu	Kobe	32 40 N.	167 00 E.	13	6p., 13	16	29.82	WNW	WNW., 8	NNE	NW., 11	WNW.-NW.
Manulani, Am. S. S.	San Francisco.	Honolulu	29 39 N.	143 35 W.	16	2p., 16	17	29.60	S	S., 7	W	W., 9	S.-SSW.
Bengal Maru, Jap. S. S.	Yokohama	San Francisco.	39 05 N.	152 00 W.	17	2a., 17	18	28.74	SSW	S., 11	WSW	SW., 11	S.-SW.-W.
West Chopaka, Am. S. S.	Hondagua	do	44 23 N.	147 55 W.	16	7a., 18	18	28.37	W	SW., 10	NNW	SW., 11	Steady.
Oridono Maru, Jap. S. S.	Miike	Grays Harbor.	48 14 N.	135 30 W.	18	4a., 20	20	28.29	ENE	SW., 8	WSW	SW., 8	S.-SW.
Unkia Maru, Jap. S. S.	Muroran	Portland	44 20 N.	158 38 E.	23	6a., 24	24	28.38	E	ENE., 9	N	ENE., 9	E.-N.
Kongosan Maru, Jap. S. S.	Yokohama	San Francisco.	44 25 N.	146 15 W.	23	4p., 24	25	29.20	NW	NW., 8	W	SSW., 10	NW.-W.
West Ivan, Am. S. S.	Hongkong	do	39 00 N.	177 00 W.	25	11a., 25	25	29.44	W	W., 8	SW	W., 8	4 pts.
Havre Maru, Jap. S. S.	Muroran	Tacoma	49 57 N.	143 10 W.	24	6a., 24	25	28.57	E	SSE., 9	SW	SSE., 9	6 pts.
City of Spokane, Am. S. S.	Yokohama	Seattle	49 46 N.	137 55 W.	24	3p., 24	26	28.74	SE	SE., 9	SE	SE., 10	SE.-WSW.
Cuprum, Am. S. S.	do	Puget Sound	50 00 N.	146 00 W.	24	10a., 24	26	28.82	SW	W., 5	W	SE., 10	
Yankee Arrow, Am. S. S.	Hongkong	Los Angeles	36 38 N.	161 43 E.	26	8a., 27	27	29.42	SSE	SW., 6	W	SE., 9	SW.-W.
Harold Dollar, Br. S. S.	Karatsu	San Francisco.	42 30 N.	155 00 E.	27	3p., 28	28	28.99	W	W., 9	W	W., 9	Steady.
SOUTH ATLANTIC OCEAN													
Stakesby, Br. S. S.	Gulfport	River Plate	31 15 S.	49 50 W.	1	3a., 2	3	29.50	NE	S., 9	S	S., 10	NW.-S.
Alchiba, Du. S. S.	Rotterdam	Rosario	28 30 S.	46 07 W.	2	4p., 2	4	29.53	SW	SW., 8	SW	SW., 8	NW.-SW.

NORTH PACIFIC OCEAN

By WILLIS E. HURD

The average of the daily barometric readings for the month over the eastern half of the North Pacific Ocean shows a sharp fall in pressure since January, when the minimum in the Aleutian area was 29.53 inches, occurring at St. Paul. The point of lowest February pressure was at Dutch Harbor, its average of 29.19 inches being the lowest for that month in recent years, although that for February, 1926, was only 0.01 inch higher. The highest daily reading at Dutch Harbor for February of this year was very low for a maximum, only 29.92 inches. The fact that the pressure was below normal from the Arctic Ocean to the Hawaiian Islands and thence eastward to a little south of San Francisco shows that the Aleutian LOW was unusually deep and extensive and that for the most part it dominated the weather of the upper two-thirds of the eastern part of the ocean, beside forcing the usual northern limit of the northeast trade winds considerably to the southward.

The North Pacific HIGH, as a consequence of the over-development and extent of the LOW, was at several times during the month practically nonexistent except as a narrow belt extending along low latitudes. From the 6th to the 12th it covered the usual area between Hawaii and the American continent and even extended well up along the Alaskan coast, but it was not otherwise well developed until near the end of the month when, for the first time in any great measure, the LOW retreated and the HIGH covered the major part of the ocean east of the 180th meridian.

The following table gives the most important pressure data at several island and coast stations in west longitudes:

TABLE 1.—*Averages, departures, and extremes of atmospheric pressure at sea level at indicated hours, North Pacific Ocean, February, 1927*

Stations	Average pressure	Departure from normal	Highest	Date	Lowest	Date
	Inches	*Inch*	*Inches*		*Inches*	
Dutch Harbor [1]	29.19	−0.43	29.92	28th	28.58	6th.
St. Paul [1]	29.36	−0.30	30.04	28th	28.80	9th.
Kodiak [1]	29.27	−0.43	29.98	10th	28.42	25th.
Midway Island [1]	29.93	−0.10	30.22	27th	29.68	13th.
Honolulu [2]	30.04	−0.01	30.22	18th	29.80	16th.
Juneau [3]	29.70	−0.22	30.37	11th	28.72	20th.
Tatoosh Island [2 3]	29.83	−0.15	30.40	9th	29.15	20th.
San Francisco [2 3]	30.03	−0.04	30.31	19th	29.43	16th.
San Diego [2 3]	30.06	+0.02	30.29	18th	29.81	11th.

[1] P. m. observations only.
[2] A. m. and p. m. observations.
[3] Corrected to 24-hour mean.

Previous reports have shown that December and January of the present winter were very stormy months over most of the ocean. February was also stormy over the eastern half of the sea, but over the western half gales were considerably less frequent, although a number of days had winds of force 10, and three, so far as known, of force 11. These were the 6th, 13th, and 14th, and the area of gales was roughly bounded by 30° and 40° N., 150° and 170° E. Those of the 6th accompanied the eastward movement of a cyclone which originated as a shallow LOW northeast of Taiwan on the 3d and proceeded oceanward for a time with increasing intensity. Those of the 13th and 14th blew off the southeastern slope of a great anticyclone which, spreading eastward from the continent, lay on these dates south and east of Japan. Lesser gales blew in the same neighborhood from the 5th to the 10th, the 15th to the 17th, and scatteringly from the 22d to the 28th.

A number of small low-pressure areas came out of Siberia this month, and though generally mild they caused frequent local snows over the Japanese Archipelago and much squally weather over the seas. A few shallow depressions left China, although this area was for the most part covered with successively passing anticyclones, and apparently the only gales on the coast were those of the northeast monsoon, which occurred on several days and were especially strong in the Taiwan Channel. The strongest wind reported locally in Asiatic waters was the result of a LOW in the upper Japan Sea. Here a westerly gale of force 10 was encountered in Tsugaru Strait on the 9th by the French steamer *Yalou*.

Owing to the great southward extension of the Aleutian LOW and to the formation of secondaries within it in middle latitudes, gales were frequent between 160° west longitude and North America. Here velocities rising to whole gale or hurricane force were experienced by vessels on the 2d, 10th, 17th, and 18th. Those of the 2d resulted from a local intensification of storm conditions near 42° N., 138° W., in which the American steamer *Pawlet* experienced the highest reported wind, a south gale of force 11. About the 8th or 9th a secondary LOW formed near 40° N., 160° W. In its progress eastward it caused strong gales on the 10th to 12th near 30° N., 145° W., the maximum being a south-southeast hurricane on the 10th. Other moderate gales attended its movement between 135° and 130° W. on the 13th to 15th. The storm winds of the 17th and 18th were encountered about midway on a nearly straight line between Juneau and Honolulu.

During much of February the weather of Midway Island was strongly influenced by the northern LOW. The average pressure because of it was only 29.93 inches, whereas the normal is 0.10 inch higher. The wind was active here, as also during January, and gales of force 9 to 10 occurred on the island or in the neighborhood, as shown by reports, on the 7th to 9th.

Most of the west-longitude gales of the latter part of February occurred in middle or higher latitudes after the disappearance of the secondary cyclones and following upon the general retreat northward of the Aleutian LOW. The Weather Bureau station at Point Reyes, Calif., reported a 76-mile wind on the 16th, and at the Tatoosh Island station velocities equaling or exceeding 60 miles an hour occurred as follows: 3d, 65 miles; 5th, 62; 18th, 60; 20th, 77 (from the southwest); 24th, 64.

At Honolulu the weather continued dry, with abnormally high temperatures. The total precipitation was 1.74 inches, which is 2.01 less than the normal. The prevailing wind direction was northeast, and the average velocity was 7.8 miles. The maximum velocity was at the rate of 35 miles an hour from the southwest on the 14th.

Contrary to the condition of dryness over the Hawaiian Islands, frequent and heavy rains occurred east of them, especially toward the California coast and thence inland. At San Diego precipitation continued from the 10th to the 16th, resulting at first from a depression which lay over northwestern Mexico and southern California and later from the LOW that was sweeping in from the Pacific. Rainfall at both San Diego and San Francisco was about double the normal for February.

Fog, as in February of last year, was rare except along the American coast, and there principally between about 30° and 40° N., where it was observed on about 50 per cent of the days. At Juneau there was fog on the 6th, 7th, 10th, 11th, and 12th. Occasional fog occurred early in the month at scattered places in west longitudes, and was reported on the 5th and 6th by a vessel in Yokohama Harbor. Except for the Japanese coast there is no record at hand of its observance between 140° E. and 160° W.

NOTES

American steamer *President Jackson*, Yokohama to Seattle, February 14–23, 1927.—Except for snow, rain, and mist squalls, "this passage was marked by exceptional weather conditions for February. Practically smooth all the way, and only light breezes."

American steamer *President Madison*, Yokohama to Seattle, February 2–10, 1927.—"In latitude 38° N., longitude 145° 30′ E., weather set in with occasional snow and heavy hail squalls, which continued every day the same to latitude 50° N., longitude 161° 30′ W.," then steady fog and thick mist.

CLIMATOLOGICAL TABLES[1]

CONDENSED CLIMATOLOGICAL SUMMARY

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitation are based only on records from stations that have 10 or more years of observations. Of course, the number of such records is smaller than the total number of stations.

Condensed climatological summary of temperature and precipitation by sections, February, 1927

Section	Temperature							Precipitation					
	Section average	Departure from the normal	Monthly extremes: Station	Highest	Date	Station	Lowest	Date	Section average	Departure from the normal	Greatest monthly: Station	Amount	Least monthly: Station	Amount
	°F.	°F.		°F.			°F.		In.	In.		In.		In.
Alabama	58.7	+10.4	2 stations	85	[2]5	St. Bernard	22	21	6.45	1.15	Bay Minette	12.39	Alaga	3.29
Arizona	51.1	+3.2	Goodyear	88	24	Chin Lee	8	9	2.59	+1.39	Prescott	10.59	Naco	T.
Arkansas	52.1	+9.3	Rison	90	16	Dutton	9	19	2.62	−0.73	Dumas	7.02	Thornburg	1.23
California	48.8	+0.5	Imperial	87	26	Helm Creek	−22	2	8.70	+4.50	Fordyce Dam	28.33	Imperial	0.64
Colorado	30.7	+4.0	Lamar	77	21	Hayden	−33	10	1.57	+0.53	Savage Basin	7.60	Hartsel	0.02
Florida	67.1	+7.0	Lake Alfred	91	24	3 stations	33	21	3.50	+0.33	Cottage Hill	10.03	Fort Myers	0.76
Georgia	58.5	+10.5	3 stations	87	[2]4	Clayton	21	[2]21	4.51	−0.49	Tallapoosa	8.22	Savannah	1.45
Idaho	30.8	+2.4	Parma	63	22	Stanley	−33	10	3.43	+1.55	Roland	11.06	Mud Lake	0.22
Illinois	38.5	+10.0	Sparta	76	5	Mount Carroll	4	15	1.46	−0.52	Dwight	3.26	Grafton	0.40
Indiana	38.8	+9.2	Huntingburg	76	17	Brookville	7	11	1.64	−0.90	Monticello	2.86	Farmersburg	0.30
Iowa	30.6	+8.0	Ottumwa	65	23	Inwood	−17	18	1.15	−0.05	Washington	3.60	Decorah	0.13
Kansas	38.5	+6.0	Richfield	78	2	St. Francis	−10	9	0.78	−0.33	Ellsworth	1.95	Richfield	0.10
Kentucky	45.6	+9.6	Hopkinsville	81	17	2 stations	15	21	2.65	−0.88	Hazard	4.67	Grant	0.80
Louisiana	62.2	+9.0	2 stations	89	[2]17	Lake Providence	26	[2]19	6.34	+1.85	Clinton	16.25	Morgan City	2.16
Maryland-Delaware	40.0	+7.0	do	73	17	Boyds, Md	15	22	3.84	+0.80	Grantsville, Md	6.93	Solomons, Md	2.21
Michigan	26.9	+7.8	Monroe	66	16	Humboldt	−27	19	1.23	−0.49	Eagle Harbor	4.24	Rogers Dam	0.30
Minnesota	17.8	+6.1	Lynd	58	23	Pokegama Falls	−35	18	0.67	−0.08	Isabella	1.75	Milan	T.
Mississippi	58.4	+9.5	2 stations	85	[2]23	Holly Springs	27	19	6.26	+1.45	Magnolia	14.19	Hernando	0.87
Missouri	41.3	+9.5	Hollister	78	8	Grant City	1	18	1.08	−1.07	Campbell	2.43	St. Charles	0.22
Montana	22.7	+1.6	Big Timber	60	20	Browning	−36	17	0.87	+0.14	Trout Creek	6.37	2 stations	0.02
Nebraska	31.9	+6.8	Curtis	75	21	Madrid	−15	10	0.92	+0.20	2 stations	2.20	Halsey	0.12
Nevada	38.2	+2.6	2 stations	80	[2]25	Lamoille	−12	9	1.37	+0.48	Arthur	3.88	Millett	0.05
New England	25.7	+3.3	3 stations	56	[2]24	Bloomfield, Vt	−32	5	3.17	−0.07	Lakeport, N. H	5.49	Cornwall, Vt	1.17
New Jersey	36.1	+6.5	2 stations	66	17	Culvers Lake	4	12	3.12	−0.43	Hightstown	4.55	Runyon	2.18
New Mexico	41.5	+3.5	Carlsbad	82	[2]23	2 stations	−5	[2]18	0.86	+0.20	Chama	5.60	3 stations	0.00
New York	28.6	+6.7	Walden	62	24	Gabriels	−25	5	2.98	+0.20	Hoffmeister	4.93	Sherburne	1.22
North Carolina	51.4	+9.0	2 stations	86	[2]17	Jefferson	13	1	3.96	−0.12	Andrews	7.29	Sanatorium	1.70
North Dakota	13.3	+5.4	Amidon	50	20	Willow City	−31	9	0.36	−0.13	Linton	1.51	2 stations	0.00
Ohio	36.7	+7.9	Portsmouth	75	17	Millport	2	22	2.49	+0.09	Kings Mills	4.05	Bellefontaine	1.24
Oklahoma	47.5	+8.0	Sulphur	83	24	Kenton	4	10	1.49	+0.04	Idabel	5.18	Kenton	0.06
Oregon	38.9	+2.0	Pilot Rock	71	21	Joseph	−5	9	6.05	+1.93	Valsetz	27.52	Blitzen	0.29
Pennsylvania	35.0	+7.3	Claysville	69	16	Saegerstown	−8	22	3.48	+0.82	Johnstown	5.94	Montrose	1.25
South Carolina	57.6	+10.2	Ferguson	88	4	2 stations	20	21	4.24	−0.07	Walhalla	7.57	Charleston	2.17
South Dakota	25.7	+7.9	2 stations	67	[2]2	Flandreau	−21	18	0.33	−0.30	Centerville	1.04	3 stations	T.
Tennessee	50.3	+9.4	Carthage	83	17	Rugby	17	28	4.62	+0.24	Loudon	8.08	Perryville	1.45
Texas	56.5	+6.0	Eagle Pass	98	22	Dalhart	8	10	2.07	+0.21	Marble Falls	6.55	Muleshoe	0.00
Utah	33.4	+3.6	St. George	74	25	East Portal	−31	10	2.04	+0.83	Silver Lake	7.70	Wendover	0.42
Virginia	44.7	+7.7	Woodstock	85	18	2 stations	14	1	3.77	+0.58	Saltville	6.80	Mineral	1.84
Washington	36.2	+2.3	5 stations	62	6	Stockdill's Ranch	−6	9	5.55	+1.32	Wynoochee Power Plant.	21.42	Mottinger	0.40
West Virginia	40.9	+8.5	Williamson	79	17	2 stations	6	22	4.49	+1.29	Pickens	8.64	2 stations	2.40
Wisconsin	23.8	+8.2	Prairie du Chien	58	22	Mellen	−33	9	0.62	−0.51	Ashland	2.35	Wisconsin Rapids	T.
Wyoming	25.2	+3.5	2 stations	64	[2]4	Moran	−48	10	0.82	+0.07	Jackson	4.50	Deaver	0.01
Alaska (*January*)	18.8	+3.4	Hydaburg	50	31	Eagle	−56	29	3.49	−1.71	Chignik	19.61	Fort Yukon	0.17
Hawaii	70.2	+1.8	Pahala	94	16	Volcano Observatory	42	13	3.92	−2.55	Honokohau Ridge	22.00	Puu Kea	0.00
Porto Rico	72.7	−0.7	2 stations	93	3	Toro Negro	47	19	1.93	−0.95	Rio Grande	4.26	3 stations	0.00

[1] For description of tables and charts, see REVIEW, 43.

[2] Other dates also.

TABLE 1.—*Climatological data for Weather Bureau stations, February, 1927*

Districts and stations	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	° *F.*	° *F.*	°*F.*		°*F.*	°*F.*		°*F.*	°*F.*	°*F.*	°*F.*	%	*In.*	*In.*		*Miles*								*0–10*	*In.*	*In.*
New England							**28.6**	**+3.3**										**80**	**2.76**	**−0.6**										**6.4**		
Eastport	76	67	85	29.92	30.00	+.02	21.1	−0.4	39	2	28	−3	5	14	27	20	16	80	2.71	−0.9	14	9,948	w.	64	ne.	26	5	5	18	7.5	26.7	16.0
Greenville, Me.	1,070	6	----	28.80	30.03	----	15.0	----	44	25	24	−14	4	6	40	----	----	----	2.62	----	13	5,635	nw.	32	nw.	5	6	8	14	----	26.2	32.5
Portland, Me.	103	82	117	29.92	30.05	+.03	24.7	+0.9	43	2	31	3	5	18	22	22	18	79	5.02	+1.4	14	6,612	n.	40	ne.	20	8	4	16	6.4	31.8	16.2
Concord	289	70	79	29.69	30.02	−.02	25.2	+2.4	51	24	33	0	5	17	33	----	----	----	2.03	−1.2	11	2,448	nw.	22	nw.	4	8	9	11	6.0	22.8	17.5
Burlington	403	11	48	29.57	30.04	+.01	22.1	+2.7	47	25	30	−8	5	14	30	----	----	----	1.38	0.0	11	6,948	s.	37	s.	1	3	12	13	6.9	16.3	2.6
Northfield	876	12	60	----	30.03	−.01	21.4	+5.0	47	25	31	−14	5	11	40	----	----	86	1.94	−0.3	11	4,742	s.	24	s.	15	2	12	14	7.1	22.7	14.2
Boston	125	115	188	29.87	30.01	−.03	32.6	+3.8	49	4	39	11	5	26	30	29	24	73	3.28	−0.2	11	7,027	sw.	42	sw.	4	5	12	11	6.4	19.2	0.0
Nantucket	12	14	90	29.97	29.98	−.06	34.8	+4.1	48	23	40	15	5	30	22	32	31	89	3.52	+0.4	13	10,938	w.	74	ne	20	9	6	13	6.7	2.0	0.0
Block Island	26	11	46	29.96	29.99	−.07	34.2	+3.8	46	17	39	19	5	30	22	31	28	80	1.90	−2.4	11	13,417	w.	76	ne.	20	8	10	10	5.8	1.4	0.0
Providence	160	215	251	29.83	30.02	−.03	32.4	+3.4	48	3	39	12	21	26	27	29	25	75	2.02	−2.4	13	8,926	nw.	60	nw.	4	7	10	11	6.2	6.8	T.
Hartford	159	122	----	29.85	30.03	−.03	32.8	+5.6	54	24	39	14	5	26	30	----	----	----	3.11	−0.4	11	------	nw.	----	----	----	8	11	9	5.7	8.6	0.0
New Haven	106	74	153	29.91	30.03	−.04	33.6	+4.6	52	24	40	15	21	27	29	30	26	78	3.42	−0.3	12	6,720	ne.	44	nw.	4	9	10	9	5.7	8.8	0.0
Middle Atlantic States							**39.9**	**+6.6**										**78**	**3.20**	**−0.1**										**6.4**		
Albany	97	102	115	29.93	30.04	−.03	30.4	+6.3	49	24	37	8	5	24	26	27	24	82	2.46	−0.1	15	5,307	s.	35	sw.	4	4	11	13	6.6	14.1	1.0
Binghamton	871	10	84	29.06	30.02	−.06	31.4	+7.4	49	3	38	15	5	25	22	----	----	----	3.34	+1.4	18	4,492	nw.	35	w.	3	0	8	20	8.6	23.3	2.5
New York	314	414	454	29.68	30.03	−.05	36.6	+5.3	56	24	43	22	21	30	26	32	26	71	3.33	−0.4	11	11,304	nw.	77	nw.	4	7	9	12	6.2	2.2	0.0
Harrisburg	374	94	104	29.63	30.04	−.05	36.6	+6.4	61	17	43	22	20	30	28	32	28	75	3.01	+0.3	12	4,634	w.	33	ne.	19	5	4	19	7.2	14.2	0.4
Philadelphia	114	123	190	29.91	30.04	−.06	40.6	+6.7	62	17	47	27	5	34	24	36	33	78	3.62	+0.2	12	6,635	sw.	32	ne.	19	5	11	12	6.3	1.9	0.0
Reading	325	81	98	29.66	30.02	----	37.6	----	61	17	44	23	5	31	28	33	30	76	3.00	−0.5	15	4,739	nw.	37	se.	20	6	9	13	6.8	13.5	T.
Scranton	805	111	119	29.14	30.03	−.05	33.2	+5.9	50	25	39	19	5	27	25	30	27	84	2.55	−0.2	15	5,214	s.	44	w.	3	3	8	17	7.5	13.8	0.4
Atlantic City	52	37	172	29.97	30.03	−.08	40.4	+6.8	64	17	47	28	28	34	28	36	33	81	3.94	+0.7	9	12,806	w.	84	ne.	20	10	8	10	5.5	2.5	0.0
Cape May	17	13	49	30.06	30.08	−.03	40.4	+6.3	65	17	47	28	5	34	27	36	33	84	3.05	----	11	------	nw.	----	----	----	----	----	----	----	2.8	0.0
Sandy Hook	22	10	55	30.00	30.02	----	36.1	----	54	24	41	24	5	31	21	32	28	78	3.68	----	11	10,460	w.	64	nw.	4	7	9	12	5.9	0.5	T.
Trenton	190	159	183	29.81	30.02	----	37.6	----	59	17	45	23	5	30	26	33	29	78	2.59	−0.6	11	8,189	nw.	52	ne.	20	8	9	11	6.3	3.7	0.0
Baltimore	123	100	215	29.89	30.03	−.08	42.1	+6.7	68	17	49	27	5	35	26	37	33	75	3.78	+0.3	10	7,131	sw.	43	ne.	20	8	10	10	6.0	3.6	0.0
Washington	112	62	85	29.90	30.04	−.07	42.1	+6.8	71	17	50	28	5	34	30	37	33	76	3.34	−0.1	9	4,857	nw.	33	nw.	27	6	11	11	5.9	1.0	0.0
Cape Henry	18	8	54	29.99	30.01	----	46.6	----	81	18	54	29	1	49	38	42	40	85	3.30	−0.5	13	7,851	sw.	64	ne.	19	9	6	13	6.1	T.	0.0
Lynchburg	681	153	188	29.28	30.04	−.07	47.0	+6.7	75	18	57	29	20	37	36	40	35	69	3.14	−0.4	12	5,427	w.	35	nw.	26	9	7	12	5.6	2.4	0.0
Norfolk	91	170	205	29.94	30.04	−.07	48.3	+5.6	77	18	56	33	28	40	33	43	39	77	3.24	−0.5	13	7,720	ne.	42	ne.	19	7	9	15	6.4	T.	0.0
Richmond	144	11	52	29.88	30.04	−.07	45.9	+6.3	73	17	55	26	1	37	34	40	36	76	2.87	−0.2	14	5,555	ne.	34	ne.	19	7	9	12	6.0	0.0	0.0
Wytheville	2,304	49	55	27.62	30.03	−.09	43.9	+8.8	71	17	52	23	28	36	34	39	35	79	3.64	−0.4	17	4,737	w.	30	sw.	14	9	5	14	6.3	2.8	0.0
South Atlantic States							**36.7**	**+8.9**										**78**	**3.22**	**−0.7**										**5.4**		
Asheville	2,253	70	84	27.66	30.04	−.09	48.2	+9.7	76	17	57	25	21	40	32	42	38	74	3.25	0.0	11	5,330	nw.	30	s.	18	8	6	14	6.2	0.2	0.0
Charlotte	779	55	62	29.19	30.04	−.08	53.4	+9.5	79	17	62	30	28	44	31	46	42	73	3.84	−0.6	9	3,879	sw.	24	sw.	6	8	9	11	6.2	T.	0.0
Hatteras	11	11	50	30.02	30.03	−.08	54.4	+7.0	70	17	61	39	28	48	22	50	48	84	3.35	−1.1	9	9,681	sw.	39	nw.	26	10	9	9	5.3	0.0	0.0
Raleigh	376	103	110	29.63	30.04	−.07	51.6	+8.4	78	17	61	29	28	42	36	46	42	78	3.90	−0.4	10	5,434	sw.	32	nw.	26	5	10	13	6.8	0.0	0 0
Wilmington	78	81	91	29.97	30.06	−.06	57.6	+9.7	81	17	67	34	28	48	28	51	48	81	2.15	−1.2	8	5,042	w.	28	sw.	23	12	5	11	5.3	0.0	0.0
Charleston	48	11	92	30.02	30.07	−.05	61.2	+8.8	82	4	69	43	21	54	26	55	52	83	2.17	−1.2	5	4,998	sw.	19	ne.	1	13	8	7	4.5	0.0	0.0
Columbia, S. C	351	41	57	29.67	30.06	−.05	57.6	+9.4	81	4	66	34	21	49	32	50	46	75	3.69	−0.9	10	5,059	sw.	32	sw.	13	11	7	10	5.4	0.0	0.0
Due West	711	10	55	29.30	30.06	----	54.3	----	77	4	63	30	21	43	27	----	----	----	3.86	------	10	6,307	sw.	38	w.	13	9	8	11	5.9	0.0	0.0
Greenville, S. C.	1,039	139	146	28.93	30.03	----	53.6	+10.3	76	4	62	30	21	46	25	48	43	76	6.27	------	10	6,305	sw.	37	ne.	19	7	12	9	5.9	T.	0.0
Augusta	182	62	77	29.86	30.05	−.07	58.8	+8.9	80	4	68	38	21	50	30	53	50	82	4.91	+0.5	10	3,710	nw.	27	nw.	13	11	6	11	5.4	0.0	0.0
Savannah	65	150	194	30.01	30.08	−.04	62.8	+8.8	81	17	72	39	21	54	25	54	49	74	1.45	−1.8	6	8,388	w.	34	se.	19	14	8	6	4.0	0.0	0.0
Jacksonville	43	209	245	30.04	30.10	−.02	64.9	+6.9	81	5	73	42	21	57	26	57	53	76	3.54	+0.1	8	7,150	sw.	56	nw.	25	17	5	6	3.9	0.0	0.0
Florida Peninsula							**72.2**	**+3.7**										**79**	**2.44**	**+0.1**										**3.6**		
Key West	22	10	64	30.07	30.09	+.02	75.2	+4.7	84	17	81	63	22	70	16	68	66	79	0.85	−0.8	3	6,379	se.	56	sw.	19	20	7	1	2.2	0.0	0.0
Miami	25	71	79	30.09	30.12	----	72.5	+5.4	83	26	73	54	22	67	22	66	64	77	2.52	+0.4	7	4,137	e.	25	s.	19	13	12	3	4.3	0.0	0.0
Tampa	35	79	87	30.06	30.10	.00	68.9	+7.0	83	4	78	47	22	60	28	62	59	82	3.96	+0.7	6	3,773	e.	22	nw.	14	11	12	5	4.2	0.0	0.0
Titusville	44	5	----	30.05	30.10	----	68.0	----	87	18	79	42	22	57	34	----	----	----	1.93	------	5	------	sw.	----	----	----	----	----	----	17	5	6	3.5	0.0	0.0
East Gulf States							**59.9**	**+8.7**										**79**	**7.06**	**+2.3**										**6.1**		
Atlanta	1,173	190	216	28.82	30.06	−.06	55.0	+9.7	76	17	63	28	21	47	26	49	45	76	6.20	+1.6	12	7,755	nw.	38	nw.	25	7	8	13	6.5	0.0	0.0
Macon	370	78	87	29.67	30.07	−.05	57.8	+8.5	80	4	68	33	1	48	30	52	47	75	4.35	−0.2	12	3,959	sw.	32	s.	14	9	8	11	5.6	0.0	0.0
Thomasville	273	49	58	29.79	30.09	−.03	63.0	+8.0	81	3	73	37	21	54	29	56	52	79	4.18	−0.3	11	3,109	sw.	20	sw.	23	8	7	13	6.0	0.0	0.0
Apalachicola	36	42	49	30.04	30.08	----	63.0	----	75	17	69	43	20	57	18	59	57	86	5.18	------	11	4,888	s.	46	n.	18	12	9	7	4.6	0.0	0.0
Pensacola	56	149	185	30.01	30.07	−.04	62.8	+7.6	75	25	68	39	19	58	19	59	57	87	6.90	+2.4	6	8,162	s.	42	ne.	18	6	8	14	6.5	0.0	0.0
Anniston	741	9	57	29.28	30.09	−.03	56.1	+10.3	80	17	66	25	21	46	33	----	----	----	8.36	+3.7	13	3,793	s.	30	nw.	25	7	11	10	6.0	0.0	0.0
Birmingham	700	11	48	29.30	30.07	−.05	57.2	+9.2	78	23	66	29	21	49	28	51	47	74	5.41	+0.7	13	4,931	s.	26	se.	13	8	8	12	6.3	0.0	0.0
Mobile	57	125	161	30.01	30.06	−.05	63.0	+8.3	80	24	71	38	19	56	27	58	56	86	7.93	+2.6	7	6,359	s.	42	se.	13	4	17	7	5.8	0.0	0.0
Montgomery	223	100	112	29.82	30.08	−.04	60.6	+9.0	81	23	69	35	21	52	27	54	49	73	5.99	+0.5	8	4,646	sw.	38	nw.	18	5	12	11	6.2	0.0	0.0
Corinth	469	6	----	----	----	----	53.8	----	80	16	63	29	21	45	36	----	----	----	3.30	------	13	------	s.	----	----	----	1	19	8	----	0.0	0.0
Meridian	375	87	95	29.65	30.05	−.06	59.2	+9.6	82	23	68	33	19	50	36	53	49	75	7.72	+2.8	10	4,313	sw.	24	sw.	23	6	6	16	6.8	0.0	0.0
Vicksburg	247	65	73	29.79	30.07	−.03	59.2	+7.4	80	24	67	34	18	51	26	55	52	81	10.48	+5.9	7	5,022	n.	51	nw.	17	5	6	17	6.5	0.0	0.0
New Orleans	53	76	84	30.00	30.06	−.03	65.4	+8.1	81	6	73	40	19	58	30	60	57	82	10.15	+5.7	7	4,252	s.	22	sw.	18	5	15	8	6.2	0.0	0.0
West Gulf States							**57.7**	**+6.2**										**77**	**2.46**	**−0.3**										**6.1**		
Shreveport	249	77	93	29.77	30.04	−.05	58.6	+7.7	84	16	67	32	19	50	29	52	48	75	2.94	−0.7	8	4,725	s.	24	ne.	28	8	9	11	5.7	0.0	0.0
Bentonville	1,303	11	44	----	----	----	45.4	+6.9	72	16	55	16	19	36	38	----	----	----	1.72	------	8	4,611	s.	26	s.	15	9	7	12	----	8.9	4.0
Fort Smith	457	79	94	29.54	30.03	−.07	50.6	+7.8	77	15	60	25	19	41	34	44	39	71	2.15	−0.6	10	5,612	e.	32	n.	17	4	14	10	6.2	1.8	2.0
Little Rock	357	136	144	29.66	30.04	−.07	52.2	+7.3	80	16	61	27	19	44	29	46	40	70	3.03	−1.2	12	6,383	s.	36	n.	18	8	6	14	6.4	T.	0.0
Austin	605	136	148	29.40	30.04	----	58.8	+5.4	89	22	70	29	19	48	35	----	----	----	2.69	+0.4	10	5,417	n.	50	nw.	17	8	7	13	6.0	0.0	0.0
Brownsville	57	53	61	29.93	29.99	----	68.0	+5.4	89	23	76	40	19	60	30	62	60	88	0.46	------	7	5,618	se.	40	nw.	18	10	10	8	5.1	0.0	0.0
Corpus Christi	20	11	78	30.00	30.02	−.03	63.4	+5.0	86	17	70	40	19	57	30	60	58	87	2.02	0.0	10	7,118	se.	43	nw.	18	6	11	11	6.3	0.0	0.0
Dallas	512	220	227	29.48	30.03	----	54.2	----	83	16	64	22	18	45	42	----	----	----	3.41	------	10	9,223	s.	50	nw.	17	13	6	9	5.4	0.1	0.0
Fort Worth	670	106	114	29.31	30.03	−.04	51.6	+3.3	81	16	62	19	18	41	43	45	39	68	1.77	+0.2	8	6,420	s.	31	nw.	17	6	12	10	6.4	T.	0.0
Galveston	54	106	114	29.99	30.05	−.02	62.8	+6.5	73	24	68	34	18	58	33	59	58	90	1.74	−1.4	9	6,592	se.	60	n.	18	9	7	12	5.9	0.0	0.0
Groesbeck	461	11	56	29.54	30.03	----	56.0	----	79	16	66	26	18	46	36	----	----	----	4.72	------	10	6,971	n.	50	w.	17	6	6	16	6.6	T.	0.0
Houston	138	292	314	29.90	30.05	----	62.6	+6.7	87	24	71	31	19	54	34	----	----	----	1.82	−1.3	10	7,614	s.	44	nw.	18	7	12	9	6.0	0.0	0.0
Palestine	510	64	72	29.50	30.04	−.04	57.2	+6.0	84	16	66	26	18	48	32	51	46	72	3.98	+0.6	10	5,279	s.	30	nw.	18	4	14	10	6.4	T.	0.0
Port Arthur	34	58	66	30.00	30.04	----	63.6	----	78	15	71	33	19	56	33	----	----	----	2.16	------	8	5,354	s.	32	nw.	18	6	7	15	6.7	0.0	0.0
San Antonio	693	119	132	29.28	30.01	−.04	61.6	+6.2	89	22	72	31	19	51	37	54	48	70	1.96	+0.2	8	4,940	s.	48	nw.	9	7	9	12	6.1	0.0	0.0
Taylor	583	55	63	29.45	30.06	.00	57.2	+5.9	86	22	68	27	19	40	36	----	----	----	2.96	+0.4	11	5,686	s.	33	nw.	18	7	10	11	6.1	0.0	0.0

TABLE 1.—*Climatological data for Weather Bureau stations, February, 1927*—Continued

Districts and stations	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
Ohio Valley and Tennessee	*Ft.*	*Ft.*	*Ft.*	*In.*	*In.*	*In.*	*° F.*	*° F.*	*° F.*		*° F.*	*° F.*		*° F.*	*° F.*	*° F.*	*° F.*	*%*	*In.*	*In.*		*Miles*								*0–10*	*In.*	*In.*
							43.8	+7.8										76	3.18	−0.4										7.1		
Chattanooga	762	189	213	29.22	30.05	−.08	53.0	+8.9	79	17	61	29	21	45	27	47	42	70	4.23	−0.7	19	5,061	sw.	32	nw.	23	5	10	13	6.7	0.3	T.
Knoxville	995	102	111	28.97	30.04	−.08	50.4	+8.5	79	17	58	28	28	42	31	46	42	77	7.53	+2.6	18	4,838	sw.	32	sw.	16	7	10	11	6.1	T.	0.0
Memphis	399	76	97	29.62	30.04	−.07	51.8	+7.5	77	16	58	28	19	45	26	46	41	72	2.89	−1.5	13	6,025	sw.	40	n.	25	6	5	17	7.1	T.	T.
Nashville	546	168	191	29.47	30.07	−.05	50.7	+9.1	78	17	59	26	28	42	38	45	40	71	4.26	−0.1	11	6,762	w.	37	nw.	25	4	11	13	6.7	T.	0.0
Lexington	989	193	230	28.96	30.05	−.06	43.4	+8.0	72	17	51	21	21	36	38				1.57	−1.4	13	9,967	sw.	52	nw.	25	6	8	14	6.4	7.6	0.0
Louisville	525	188	234	29.47	30.06	−.05	44.6	+7.4	71	5	52	24	19	37	26	40	35	72	2.02	−1.7	10	8,135	n.	44	w.	25	5	9	14	6.6	8.8	0.0
Evansville	431	76	116	29.60	30.08	−.03	44.5	+8.2	70	17	52	23	19	37	26	40	36	76	0.90	−2.2	9	6,504	n.	35	nw.	25	5	9	14	6.6	4.0	0.0
Indianapolis	822	194	230	29.14	30.05	−.05	39.2	+8.1	66	5	46	17	19	32	26	35	30	73	2.36	−0.7	9	8,884	sw.	47	nw.	25	5	8	15	7.0	2.0	0.0
Royal Center	736	11	55	29.22	30.04	------	35.1	------	60	5	43	16	19	28	26				2.24	------	9	7,861	w.	42	n.	18	8	6	14	6.2	2.8	T.
Terre Haute	575	96	129	29.41	30.04	------	40.4	------	65	5	48	19	19	33	23	36	32	78	1.80	------	9	7,464	nw.	45	n.	18	3	9	16	7.3	4.4	0.0
Cincinnati	627	11	51	29.36	30.05	−.05	40.8	+8.0	67	5	49	20	11	33	28	36	33	79	2.20	−1.0	13	6,297	sw.	34	ne.	18	5	7	16	7.0	5.4	0.0
Columbus	822	179	222	29.15	30.04	−.05	37.8	+7.1	66	16	45	15	11	30	26	35	32	81	1.62	−1.4	13	7,785	w.	49	w.	25	1	10	17	8.1	4.5	0.0
Dayton	899	137	173	29.08	30.06	------	39.0	+7.6	66	16	47	18	11	32	25	35	31	78	1.66	−1.4	11	7,344	sw.	39	ne.	18	3	9	16	7.5	4.1	0.0
Elkins	1,947	59	67	27.95	30.06	−.04	39.0	+7.4	66	17	48	19	21	30	39	35	32	82	5.71	+2.5	21	4,342	w.	34	w.	25	2	6	20	8.2	5.8	1.4
Parkersburg	637	77	82	29.39	30.06	−.04	41.2	+7.0	71	16	50	19	11	32	33	36	32	76	3.33	+0.1	18	4,317	n.	34	w.	25	4	5	17	9.6	11.4	0.0
Pittsburgh	842	353	410	29.11	30.04	−.05	38.1	+5.8	66	16	45	20	11	31	31	34	31	80	3.97	+1.3	14	8,697	w.	41	w.	3	0	9	19	8.1	21.0	0.5
Lower Lake Region							30.9	+5.9										79	2.61	+0.2										7.6		
Buffalo	767	247	280	29.15	30.00	−.06	29.4	+5.1	46	16	35	12	20	24	23	27	25	86	2.87	0.0	16	13,082	sw.	72	sw.	3	1	7	20	8.2	17.8	3.0
Canton	448	10	61	29.53	30.03	------	19.3	+1.3	47	25	27	−16	5	12	27				2.21	−0.4	14	7,047	e.	48	ne.	20	7	9	12	6.2	20.1	8.0
Oswego	335	76	91	------	30.02	−.04	28.8	+4.9	52	23	35	8	5	22	25			85	2.49	−0.1	17	7,639	se.	44	nw.	3	1	7	20	----	34.6	4.0
Rochester	523	86	102	29.43	30.02	−.04	31.0	+6.4	51	23	36	16	5	25	23	28	24	77	3.58	+0.8	17	6,919	w.	39	sw.	26	1	8	19	8.4	21.8	3.5
Syracuse	597	97	113	29.37	30.03	−.04	30.4	+6.6	51	23	36	10	5	24	25				3.48	+1.7	18	6,300	nw.	53	nw.	4	1	8	19	8.1	24.7	4.0
Erie	714	130	166	29.22	30.01	−.06	31.8	+4.9	53	16	37	17	22	26	26	29	25	77	2.54	−0.3	14	10,770	sw.	48	sw.	26	2	1	25	8.7	13.3	3.5
Cleveland	762	190	201	29.19	30.04	−.03	33.7	+6.3	65	16	40	18	21	28	31	31	28	81	2.83	+0.2	16	10,343	w.	44	ne.	20	2	5	21	8.2	11.0	3.5
Sandusky	629	62	70	29.34	30.04	−.03	34.2	+6.8	65	16	40	18	21	28	29				2.32	−0.1	12	6,661	w.	33	n.	18	4	4	20	7.6	9.6	2.0
Toledo	628	208	243	29.34	30.05	−.02	34.2	+6.9	63	16	41	16	20	28	27	30	26	76	2.33	+0.4	12	10,356	w.	45	w.	3	7	6	15	6.6	7.4	0.4
Fort Wayne	856	113	124	29.09	30.04	------	35.2	+9.4	62	16	42	16	19	28	23	32	28	78	1.41	------	9	7,047	w.	32	sw.	1	9	4	15	6.6	5.0	0.8
Detroit	730	218	258	29.22	30.04	−.02	31.8	+6.5	59	16	38	13	19	26	26	29	24	75	1.48	−0.7	12	7,985	w.	39	sw.	11	4	6	18	7.7	11.8	T.
Upper Lake Region							25.2	+6.0										83	1.28	−0.5										6.5		
Alpena	609	13	92	29.34	30.03	.00	23.3	+5.3	46	24	31	−3	13	16	30	22	19	83	1.04	−0.8	13	6,958	nw.	48	nw.	3	4	10	14	7.0	13.8	3.5
Escanaba	612	54	60	29.36	30.05	−.01	20.7	+5.3	47	23	30	−9	19	12	33	19	15	82	0.91	−0.4	9	6,270	n.	34	n.	17	10	5	13	5.9	10.5	10.0
Grand Haven	632	54	89	29.33	30.04	−.01	29.8	+5.6	46	16	35	10	19	25	20	28	25	83	1.38	−0.5	7	8,093	nw.	37	n.	17	7	5	16	6.8	3.3	0.0
Grand Rapids	707	70	87	29.25	30.04	−.01	31.1	+7.4	53	16	37	10	18	25	20	28	24	78	1.34	−0.6	7	4,688	w.	22	ne.	19	6	3	19	7.2	3.0	T.
Houghton	668	62	99	29.26	30.02	−.03	17.4	+3.7	43	22	26	−16	19	9	38				2.26	+0.6	12	6,652	w.	42	w.	11	7	8	13	6.4	22.5	23.0
Lansing	878	11	62	29.06	30.03	------	29.8	+6.9	56	16	36	9	18	23	23	27	25	88	1.34	−0.7	9	4,986	nw.	26	sw.	11	7	7	14	6.5	8.4	0.9
Ludington	637	60	66	29.32	30.03	------	27.8	------	43	16	33	5	19	22	25	26	23	83	0.54	------	7	7,289	e.	42	sw.	11	6	6	16	6.6	8.0	1.2
Marquette	734	77	111	29.21	30.04	−.01	21.2	+4.9	47	23	29	−2	19	14	28	19	16	85	1.73	0.0	15	6,307	w.	34	sw.	11	7	3	18	7.1	17.3	14.6
Port Huron	638	70	120	29.31	30.02	−.03	29.7	+7.0	50	23	36	14	20	24	26	27	24	84	1.09	−1.1	12	8,190	nw.	43	nw.	3	5	6	17	7.5	10.6	2.0
Saginaw	641	----	----	----	----	----	28.0	+6.1	49	16	34	9	18	22	26				1.41	------	11	----	w.	----	----	18	4	6	----	6.0	T.
Sault Sainte Marie	614	11	52	29.33	30.06	+.03	15.9	+3.3	36	23	26	−10	19	6	38	15	13	86	1.58	+0.2	10	5,120	se.	34	nw.	11	7	9	12	6.6	15.8	15.6
Chicago	673	7	131	29.30	30.05	−.03	35.0	+8.7	56	22	41	16	10	29	23	31	27	73	0.75	−1.4	10	8,639	nw.	47	ne.	17	10	5	13	5.8	1.3	T.
Green Bay	617	109	141	29.35	30.04	−.02	24.6	+7.2	44	22	32	2	10	18	26	24	22	87	0.34	−1.3	4	7,262	n.	38	s.	1	7	7	14	6.5	1.7	1.3
Milwaukee	681	125	139	29.28	30.04	−.02	30.9	+8.1	55	23	37	11	10	24	23	28	24	75	1.35	−0.5	9	7,170	w.	35	ne.	17	7	8	13	6.1	7.0	T.
Duluth	1,133	5	47	28.78	30.06	−.02	15.6	+4.2	43	23	24	−18	18	7	33	14	12	89	1.52	+0.5	10	8,643	w.	52	nw.	17	9	10	9	5.2	15.0	9.4
North Dakota							13.6	+5.8										85	0.58	-0.0										5.8		
Moorhead	940	50	58	29.02	30.09	−.02	14.0	+5.9	42	22	23	−18	18	5	36	13	12	90	1.19	+0.5	13	6,099	n.	25	n.	7	5	9	14	6.7	8.9	1.2
Bismarck	1,674	8	57	28.22	30.09	−.03	17.6	+7.3	47	20	26	−16	9	9	35	15	12	82	0.19	−0.3	4	5,602	nw.	28	nw.	25	9	8	11	5.5	1.9	T.
Devils Lake	1,478	11	44	28.42	30.09	−.02	10.1	+5.6	40	21	19	−18	18	1	34	8	6	88	0.53	0.0	7	6,692	n.	30	n.	11	12	9	7	4.9	7.4	1.3
Ellendale	1,457	10	56	28.45	30.08	------	15.7	------	43	22	25	−17	18	7	40				0.69	------	10	9,096	nw.	40	n.	17	7	8	13	6.3	4.8	T.
Grand Forks	833	12	67	------	------	------	12.5	------	40	22	20	−15	18	5	31	10	----	----	0.61	------	10	------	n.	42	se.	19	11	11	6	6.3	5.9	3.2
Williston	1,878	41	48	28.01	30.09	−.02	12.6	+4.5	43	21	22	−21	9	3	35	11	8	81	0.40	−0.1	5	4,359	w.	29	w.	3	10	9	9	4.9	3.6	1.7
Upper Mississippi Valley							33.4	+8.8										77	1.08	−0.6										5.8		
Minneapolis	918	102	208	29.04	30.06	------	23.0	+7.1	49	23	31	−10	18	15	38	----	----	----	0.35	−0.4	4	7,682	nw.	36	n.	17	7	7	14	6.5	2.1	T.
St. Paul	837	236	261	29.10	30.04	−.05	22.8	+7.0	48	23	31	−10	18	15	36	----	----	----	0.28	−0.6	4	7,992	nw.	36	w.	3	5	12	11	6.1	2.5	T
La Crosse	714	11	48	29.25	30.05	−.03	27.8	+8.6	52	23	36	1	18	20	26	24	20	78	0.32	−0.7	6	3,449	w.	21	s.	1	10	8	10	5.8	2.4	0.0
Madison	974	70	78	28.98	30.07	.00	28.1	+9.0	52	22	35	6	18	21	24	26	22	82	0.62	−0.8	5	6,374	nw.	34	sw.	1	10	9	9	5.4	1.6	0.0
Wausau	1,247	4	----	28.64	30.03	----	22.5	------	45	22	31	−4	10	14	33	----	----	----	0.29	------	6	----	n.	----	----	10	5	13	5.8	3.7	3.3
Charles City	1,015	10	49	28.96	30.08	−.02	27.8	+10.7	54	23	36	−2	18	20	28	25	22	83	0.61	−0.4	5	4,927	nw.	27	w.	22	11	6	11	5.0	1.2	0.0
Davenport	606	71	79	29.39	30.07	−.03	33.8	+8.9	57	22	41	12	18	26	29	31	28	82	2.36	+0.8	5	5,229	w.	26	n.	18	9	11	8	5.1	4.0	0.0
Des Moines	861	84	97	29.13	30.07	−.04	32.6	+8.9	59	2	41	3	18	24	30	29	24	75	1.19	+0.1	5	4,880	n.	37	sw.	1	10	5	13	6.0	5.6	T.
Dubuque	700	81	96	29.27	30.05	−.04	31.4	+9.2	55	22	39	8	18	24	28	28	24	75	0.83	−0.6	6	4,606	nw.	30	n.	17	10	10	8	4.9	3.4	T.
Keokuk	614	64	78	29.38	30.08	−.03	36.8	+8.5	64	23	45	15	18	28	28	32	27	71	1.38	−0.2	6	5,469	w.	29	n.	24	10	8	10	5.5	1.2	T.
Cairo	358	87	93	29.66	30.06	−.06	46.9	+8.4	70	5	54	23	19	40	26	42	37	74	1.36	−2.0	7	8,193	n.	50	n.	18	3	7	18	7.6	1.2	0.0
Peoria	609	11	45	29.39	30.07	−.03	36.1	+10.2	60	23	44	17	10	28	27	32	28	79	2.85	+0.2	8	5,247	w.	25	n.	17	8	10	10	5.6	1.3	0.0
Springfield, Ill.	636	10	91	29.37	30.06	−.04	39.0	+9.5	62	23	46	20	19	32	27	34	30	74	1.03	−1.7	7	6,176	w.	30	nw.	25	10	7	11	5.8	0.3	0.0
Hannibal	534	74	109	29.47	30.06	−.05	38.7	+9.0	65	23	47	18	10	31	28				1.43	−0.2	11	6,343	sw.	38	sw.	15	8	8	12	5.8	0.9	0.0
St. Louis	568	265	303	29.44	30.06	−.05	43.2	+8.7	70	5	51	21	19	35	29	37	32	70	0.56	−2.2	5	8,236	n.	46	n.	25	8	5	15	6.4	2.1	0.0
Missouri Valley							34.3	+8.5										75	0.72	−0.4										5.2		
Columbia, Mo.	784	11	84	29.21	30.06	−.05	40.0	+8.3	66	15	49	13	10	31	35	----	----	----	0.57	−1.6	7	6,038	s.	31	n.	17	7	8	13	6.1	2.9	0.0
Kansas City	963	161	181	29.00	30.05	−.05	40.3	+9.1	67	16	49	8	18	31	38	35	30	70	0.85	−0.7	7	7,674	n.	53	sw.	15	8	9	11	5.8	0.4	T.
St. Joseph	967	11	49	28.99	30.06	------	38.0	------	64	16	47	5	18	29	36	33	28	75	1.37	------	8	5,626	sw.	37	nw.	24	16	5	7	3.8	0.2	T.
Springfield, Mo.	1,324	98	104	28.61	30.04	−.07	43.8	+8.6	71	15	53	16	10	34	39	38	32	71	0.79	−1.5	8	7,508	s.	37	n.	17	12	11	5	4.5	2.9	1.2
Iola	984	11	50	28.99	30.07	−.03	41.0	+7.8	70	16	51	8	18	31	31	----	----	----	0.41	−1.1	6	5,033	s.	36	n.	17	8	9	11	6.1	0.4	T.
Topeka	987	92	107	----	----	----	38.6	+7.6	67	16	48	5	18	29	38	----	----	----	0.76	−0.6	7	6,293	sw.	38	n.	17	13	9	6	4.3	3.3	T.
Lincoln	1,189	11	84	28.78	30.08	−.02	33.2	+7.1	58	24	42	−1	18	24	36	29	24	75	1.15	+0.4	4	6,356	n.	39	n.	17	7	5	16	6.4	7.9	0.4
Omaha	1,105	115	122	28.86	30.08	−.03	32.8	+7.3	55	23	41	−3	18	24	42	29	25	75	0.91	+0.2	5	5,529	nw.	38	ne.	17	10	8	10	5.0	6.5	0.1
Valentine	2,598	47	54	27.27	30.06	−.03	30.7	+9.3	64	2	43	−3	18	18	48	25	19	69	0.47	−0.1	6	6,208	w.	30	n.	24	12	8	8	4.5	5.7	1.4
Sioux City	1,135	94	164	28.84	30.10	−.02	30.0	+9.0	56	22	38	−6	18	22	32	26	22	78	1.46	+0.9	5	7,856	nw.	47	n.	17	12	4	12	5.4	5.8	0.2
Huron	1,306	59	74	28.64	30.09	−.03	24.9	+10.6	53	23	35	−8	18	15	37	22	19	82	0.20	−0.2	5	6,448	nw.	33	nw.	22	10	9	9	4.9	1.4	T.
Pierre	1,572	70	75	------	30.09	−.02	27.2	+8.6	55	1	38	−5	9	17	55	----	----	78	0.11	−0.3	4	5,537	nw.	32	nw.	7	9	7	12	----	1.1	T.
Yankton	1,233	49	57	28.72	30.09	−.03	29.0	+8.7	58	2	38	−4	18	20	34	----	----	----	0.92	+0.3	6	5,069	w.	27	nw.	7	7	12	9	5.5	4.0	T.

TABLE 1.—*Climatological data for Weather Bureau stations, February, 1927*—Continued

Districts and stations	Elevation of instruments: Barometer above sea level	Elevation of instruments: Thermometer above ground	Elevation of instruments: Anemometer above ground	Pressure: Station, reduced to mean of 24 hours	Pressure: Sea level, reduced to mean of 24 hours	Pressure: Departure from normal	Temperature of the air: Mean max. + mean min. ÷ 2	Temperature of the air: Departure from normal	Temperature of the air: Maximum	Temperature of the air: Date	Temperature of the air: Mean maximum	Temperature of the air: Minimum	Temperature of the air: Date	Temperature of the air: Mean minimum	Temperature of the air: Greatest daily range	Mean wet thermometer	Mean temperature of the dew point	Mean relative humidity	Precipitation: Total	Precipitation: Departure from normal	Precipitation: Days with 0.01, or more	Wind: Total movement	Wind: Prevailing direction	Wind: Maximum velocity: Miles per hour	Wind: Maximum velocity: Direction	Wind: Maximum velocity: Date	Clear days	Partly cloudy days	Cloudy days	Average cloudiness, tenths	Total snowfall	Snow, sleet, and ice on ground at end of month
	Ft.	Ft.	Ft.	In.	In.	In.	°F.	°F.	°F.		°F.	°F.		°F.	°F.	°F.	°F.	%	In.	In.		Miles								0–10	In.	In.
Northern Slope							25.5	+3.7										72	0.68	−0.1										6.2		
Billings	3,140	5					27.7		51	3	38	−6	9	17	39				0.19		6		nw.				8	7	13			
Havre	2,505	11	44	27.31	30.08	+.01	15.1	+1.5	48	20	25	−26	17	5	42	14	11	82	0.55	+0.1	8	4,795	e.	32	sw.	21	5	14	9	5.9	6.9	0.1
Helena	4,110	87	112	25.70	30.01	−.10	26.4	+3.4	53	20	36	−6	17	16	46	23	18	70	0.48	−0.2	11	4,911	sw.	50	sw.	21	2	6	20	7.6	3.8	0.0
Kalispell	2,973	48	56	26.84	29.98	−.10	26.7	+3.4	48	20	34	4	13	19	26	25	22	83	1.04	−0.4	13	2,986	nw.	25	sw.	20	3	8	17	7.4	10.3	5.8
Miles City	2,371	48	55	27.46	30.12	+.03	20.7	+3.9	48	23	31	−13	9	11	37	18	15	78	0.22	−0.3	5	3,598	ne.	30	nw.	21	7	10	11	5.6	2.5	1.5
Rapid City	3,259	50	58	26.56	30.09	+.01	28.9	+5.5	59	21	40	−2	9	18	50	25	20	70	0.22	−0.2	4	5,122	w.	30	n.	21	7	12	9	5.8	2.2	1.0
Cheyenne	6,088	84	101	23.90	30.03	.00	29.0	+1.7	54	2	39	−8	9	19	37	24	16	62	1.09	+0.5	9	10,826	w.	71	w.	21	8	7	13	6.2	16.5	8.0
Lander	5,372	60	68	24.55	30.03	−.05	27.2	+4.7	54	20	38	−11	9	17	35	23	18	68	1.20	+0.6	7	3,762	sw.	58	w.	21	6	15	7	5.4	14.4	8.0
Sheridan	3,790	10	47	26.02	30.04		25.6		62	21	38	−13	9	13	48	21	15	68	0.45		10	2,336	nw.	31	sw.	21	5	16	7	5.9	5.2	1.0
Yellowstone Park	6,241	11	48	23.76	30.05	−.05	22.9	+3.3	40	21	31	−9	9	14	32	21	17	75	0.86	−1.0	19	7,014	s.	40	sw.	21	3	9	16	7.1	6.9	6.8
North Platte	2,821	11	51	27.08	30.10	+.03	32.6	+6.0	67	21	46	−1	10	20	42	26	19	68	0.48	+0.1	8	4,649	w.	37	n.	17	12	8	11	5.2	4.4	2.0
Middle Slope							39.6	+5.8										65	0.99	+0.2										5.8		
Denver	5,292	106	113	24.65	30.01	.00	36.7	+4.0	64	21	48	5	9	25	34	29	22	61	0.32	−0.2	5	5,493	s.	42	w.	22	10	13	8	5.0	3.2	3.0
Pueblo	4,685	80	86	25.22	29.97	−.03	38.5	+5.6	69	21	51	0	9	26	39	30	18	49	0.90	+0.4	6	5,643	nw.	58	nw.	21	10	11	7	4.9	3.3	4.8
Concordia	1,392	50	58	28.56	30.08	−.01	36.4	+6.3	63	16	46	6	18	27	29	31	26	72	1.41	+0.7	6	4,899	w.	38	n.	17	6	8	14	6.1	2.3	1.1
Dodge City	2,509	11	51	27.42	30.08	+.02	38.6	+5.4	72	2	51	5	10	26	40	30	24	68	1.21	+0.5	9	6,203	ne.	43	n.	17	11	9	8	4.6	6.1	2.0
Wichita	1,358	139	158	28.58	30.04	−.04	40.8	+6.4	72	15	51	9	18	31	41	36	30	70	1.02	0.0	7	8,929	s.	50	ne.	17	6	14	8	5.9	2.3	0.6
Broken Arrow	765	11	56	29.21	30.05		46.2		79	16	56	16	18	36	42				1.50		10	9,590	n.	54	n.	17	4	6	18	7.5	4.8	4.0
Oklahoma City	1,214	10	47	28.74	30.04	−.03	46.6	+7.0	81	16	57	12	18	36	44	40	35	72	1.07	+0.1	7	8,016	s.	41	n.	17	5	8	15	6.6	5.4	3.2
Southern Slope							51.4	+5.4										57	1.26	+0.4										5.4		
Abilene	1,738	10	62	28.21	30.04	−.01	52.2	+5.0	82	21	64	24	18	41	49	44	37	66	2.28	+1.2	11	7,250	s.	35	w.	13	5	7	16	6.9	0.1	0.0
Amarillo	3,676	10	49	26.24	30.00	−.02	44.6	+6.5	76	21	58	15	9	31	41	35	26	57	0.23	−0.6	4	6,982	sw.	35	sw.	15	14	7	7	4.7	2.2	1.2
Del Rio	944	64	71	29.02	30.02	+.02	59.4	+3.4	89	22	70	34	10	49	39				2.38	+1.5	7	5,760	se.	40	n.	18	13	3	12	5.3	0.0	0.0
Roswell	3,566	75	85	26.35	29.97	−.01	49.2	+6.7	77	26	62	24	9	36	46	39	28	48	0.14	−0.4	3	5,641	sw.	42	nw.	17	10	12	6	4.8	T.	0.0
Southern Plateau							48.7	+3.9										61	0.93	+0.3										5.0		
El Paso	3,778	152	175	26.20	30.00	+.05	54.1	+5.1	75	27	66	31	11	42	33	43	30	45	0.18	−0.3	3	6,657	w.	48	w.	28	13	13	2	4.1	0.0	0.0
Santa Fe	7,013	38	53	23.19	29.99	+.01	37.6	+4.5	60	26	46	18	10	29	29	31	26	67	1.62	+0.8	11	4,458	n.	31	n.	20	7	9	12	6.1	2.5	T.
Flagstaff	6,907	10	59	23.30	29.94	−.00	35.5	+4.7	59	25	46	16	8	25	33	32		81	4.44		9	5,309	sw.	38	sw.	15	6	14	8		15.0	T.
Phoenix	1,108	10	82	28.84	30.00	+.01	58.8	+3.7	80	26	70	37	1	47	38	50	42	60	1.06	+.04	6	2,742	e.	20	se.	12	6	12	10	5.8	0.0	0.0
Yuma	141	9	54	29.86	30.01	+.01	61.3	+2.7	84	26	74	39	10	49	33	51	41	53	0.16	−0.4	3	3,492	n.	28	se.	14	14	10	4	4.1	0.0	0.0
Independence	3,957	5	25	25.94	30.00	−.06	44.7	+2.5	71	26	58	20	5	32	35	36			1.62	+0.8	6		nw.				9	9	10		0.1	0.0
Middle Plateau							36.7	+3.4										68	1.82	+0.8										4.2		
Reno	4,532	74	81	25.41	30.00	−.08	38.8	+3.2	60	25	47	17	11	30	32	34	27	64	2.74	+1.8	11	4,622	w.	48	w.	18	7	6	15	6.1	7.1	0.0
Tonopah	6,090	12	20	24.00	30.00		35.8		58	25	43	15	10	28	28	30	21	56	0.08		2		se.									
Winnemucca	4,344	18	56	25.59	30.04	−.05	35.0	+1.5	60	25	45	1	13	25	36	32	29	79	2.49	+1.6	15	5,744	sw.	45	sw.	18	5	16	7	5.6	10.2	0.0
Modena	5,473	10	43	24.57	29.98	−.06	35.7	+4.7	62	25	46	13	1	26	37	31	25	67	1.09	−0.1	7	6,375	sw.	47	sw.	18	10	8	10	5.3	4.6	0.0
Salt Lake City	4,360	163	203	25.60	30.03	−.05	38.0	+4.2	56	20	44	20	11	32	22	33	27	66	1.49	+0.1	12	4,507	s.	34	s.	16	2	10	16	7.2	12.5	0.0
Grand Junction	4,602	60	68	25.36	30.00	−.04	36.2	+3.3	60	25	46	9	1	27	28	32	27	74	1.30	+0.7	11	2,775	nw.	34	sw.	16	5	13	10	6.2	6.7	T.
Northern Plateau							37.4	+4.4										71	1.60	+0.2										7.8		
Baker	3,471	48	53	26.38	30.02	−.10	34.3	+5.3	50	20	41	15	13	28	25	31	25	70	0.72	−0.6	14	4,783	se.	46	sw.	21	2	9	17	7.5	3.9	0.0
Boise	2,739	78	86	27.16	30.06	−.06	39.7	+4.9	55	21	46	23	10	33	22	36	30	69	2.01	+0.6	13	4,475	se.	30	w.	22	2	8	18	7.4	0.5	0.0
Lewiston	757	40	48	29.15	29.97	−.14	42.2	+5.2	60	20	49	27	28	35	23				1.15	−0.2	14	2,640	e.	30	nw.	20	0	11	17	7.9	0.3	0.0
Pocatello	4,477	60	68	25.43	30.05	−.05	32.0	+3.1	48	3	38	1	10	26	25	28	23	70	1.43	+0.6	14	6,619	se.	40	sw.	18	4	6	18	7.0	2.9	0.0
Spokane	1,929	101	110	27.90	29.99	−.10	34.6	+3.3	51	20	40	17	7	29	19	33	30	81	2.71	+1.0	12	3,509	sw.	29	sw.	21	1	8	19	8.5	8.7	0.0
Walla Walla	991	57	65	28.90	29.98	−.13	41.6	+4.5	62	20	48	27	5	35	29	38	32	67	1.57	0.0	14	3,925	s.	33	w.	18	2	7	19	8.2	0.6	0.0
North Pacific Coast Region							44.6	+2.7										80	6.38	+1.3										6.7		
North Head	211	11	56	29.64	29.88	−.18	45.0	+2.0	53	7	50	36	14	40	15	43	40	81	8.07	+2.1	19	12,564	se.	82	s.	19	4	3	21	7.9	0.0	0.0
Port Angeles	29	8	53		29.91		41.4		53	18	48	29	17	34	19				3.01	0.0	13	3,929	s.	26	w.	22	5	12	11		T.	0.0
Seattle	125	215	250	29.76	29.89	−.17	43.9	+2.8	57	24	50	31	14	38	18	40	35	73	4.68	+1.0	16	6,900	s.	51	sw.	1	9	10	9	5.6	0.0	0.0
Tacoma	194	172	201	29.71	29.92	−.14	43.1	+2.5	57	2	50	29	14	36	21				6.52	+2.3	16	5,534	s.	47	s.	19	6	12	10	6.1	0.0	0.0
Tatoosh Island	86	9	53	29.74	29.83	−.17	44.9	+3.9	52	12	48	37	16	42	10	42	38	79	8.18	−0.6	15	14,626	e.	77	sw.	20	8	6	14	6.1	0.0	0.0
Yakima	1,071	5					37.4		57	20	47	16	13	28	27				0.98		7		nw.				1	19	8	6.1	4.5	0.0
Medford	1,425	4					43.0		58	1	53	22	9	33	35	40	37	82	3.87		12		se.				7	7	14		0.0	0.0
Portland Oreg.	153	68	106	29.77	29.93	−.15	45.6	+3.5	57	25	52	31	11	39	20	43	39	80	6.95	+1.5	18	4,845	s.	33	sw.	1	5	6	17	7.1	0.0	0.0
Roseburg	510	9	57	29.39	29.95	−.15	45.2	+1.8	64	1	54	23	13	37	35	43	40	82	7.26	+2.7	19	2,317	s.	25	sw.	22	3	5	20	7.8	0.0	0.0
Middle Pacific Coast Region							51.4	+1.7										80	6.52	+2.5										6.5		
Eureka	62	73	89	29.93	30.00	−.11	49.8	+2.6	66	24	57	35	9	43	23	47	45	84	10.30	+3.3	16	5,715	se.	37	w.	18	7	6	15	6.5	0.0	0.0
Point Reyes	490	7	18	29.46	29.98		50.4	+1.2	55	28	53	45	11	48	9				4.09		17	14,526	s.	85	sw.	16	7	6	15	6.8	0.0	0.0
Red Bluff	332	50	56	29.66	30.02	−.09	49.9	+0.5	65	28	57	29	12	43	28	46	42	76	6.47	+2.8	16	4,707	se.	30	se.	20	7	6	15	6.2	0.0	0.0
Sacramento	69	106	117	29.97	30.04	−.05	51.8	+1.7	66	25	58	36	11	46	25	49	46	81	4.99	+1.8	16	6,305	se.	52	se.	16	8	3	17	6.5	0.0	0.0
San Francisco	155	208	243	29.86	30.03	−.07	54.0	+1.8	63	28	59	44	12	49	16	50	47	80	6.85	+3.2	18	4,789	se.	37	se.	16	7	5	16	6.7	0.0	0.0
San Jose	141	12	110	29.91	30.06		52.8	+2.2	68	28	62	31	11	44	32				4.01	+1.6	12	5,062	se.	40	se.	16	6	6	16	6.4	0.0	0.0
South Pacific Coast Region							55.4	+1.7										80	6.50	+4.0										6.3		
Fresno	327	89	98	29.72	30.08	.00	53.2	+2.1	71	25	61	32	11	45	27	49	45	75	2.49	+1.2	12	4,331	se.	28	nw.	26	8	9	11	5.7	0.0	0.0
Los Angeles	338	159	191	29.69	30.06	.00	56.6	+1.1	73	8	63	40	2	50	23	53	50	83	9.03	+6.1	10	3,575	sw.	27	sw.	16	5	6	17	6.8	0.0	0.0
San Diego	87	62	70	29.97	30.06	.00	56.4	+1.3	66	18	61	43	2	52	20	53	52	87	6.68	+4.7	12	4,880	nw.	36	s.	15	3	12	13	7.0	0.0	0.0
San Luis Obispo	201	32	40	29.86	30.08	−.03	55.3	+2.2	72	28	64	38	11	47	29	50	46	75	7.78	+4.2	15	3,197	n.	22	sw.	14	7	10	11	5.6	0.0	0.0
West Indies																																
San Juan, P. R.	82	9	54	29.97	30.06		73.9	−1.0	82	28	79	65	18	69	14				1.60	−0.9	15	9,343	e.	35	ne.	2	10	16	2	4.6	0.0	0.0
Panama Canal																																
Balboa Heights	118	7	97	29.78	29.90	+.03	79.0	−1.3	90	8	87	68	27	71	21	72	71	78	1.99	+1.2	7	5,632	nw.	30	nw.	3	3	20	5	5.9	0.0	0.0
Colon	38	7	97	29.89	29.92	+.02	80.2	+0.1	88	1	86	69	19	74	16	74	72	77	3.21	+1.6	12	9,450	n.	30	n.	1	10	12	6	5.2	0.0	0.0
Alaska				(1)	(1)																											
Juneau	80	11	54	29.61	29.70		32.0		48	13	36	10	16	27	20	30	25	79	4.34		20	6,595	se.	42	e.	15	3	2	23	8.5	8.9	T.
Hawaiian Islands				(1)	(1)																											
Honolulu	38	86	100	30.00	30.04		72.6		82	19	78	60	17	67	16	66	63	75	1.74	−2.0	10	5,229	ne.	35	sw.	14	10	13	5	4.6	0.0	0.0

[1] Pressure not corrected to mean of 24 hours.

TABLE 2.—*Data furnished by the Canadian Meteorological Service, February, 1927*

Stations	Altitude above mean sea level, Jan. 1, 1919	Pressure			Temperature of the air						Precipitation		
		Station reduced to mean of 24 hours	Sea level reduced to mean of 24 hours	Departure from normal	Mean max.+ mean min.÷2	Departure from normal	Mean maximum	Mean minimum	Highest	Lowest	Total	Departure from normal	Total snowfall
	Feet	*In.*	*In.*	*In.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*°F.*	*In.*	*In.*	*In.*
St. Johns, N. F.	125												
Sydney, C. B. I.	48	29.92	29.97	+.05	16.7	−2.6	26.2	7.2	37	−8	5.32	+1.28	44.0
Halifax, N. S.	88	29.72	29.83	−.12	20.5	−1.9	28.2	12.7	38	−2	2.62	−2.54	19.1
Yarmouth, N. S.	65	29.85	29.92	−.07	25.9	+0.1	32.2	19.6	40	5	4.17	−0.57	37.2
Charlottetown, P. E. I.	38	29.93	29.97	+.02	16.4	−1.2	23.9	8.8	38	−5	3.07	+0.01	27.9
Chatham, N. B.	28	29.92	29.96	.00	11.4	−1.1	21.1	1.8	30	−14	2.29	−0.87	22.9
Father Point, Que.	20	30.02	30.05	+.07	11.9	+0.4	19.4	4.3	31	−16	1.34	−0.87	13.4
Quebec, Que.	296	29.71	30.05	+.06	14.2	+2.4	20.8	7.7	34	−14	3.53	+0.26	35.2
Montreal, Que.	187	29.80	30.02	.00	17.5	+3.0	24.3	10.8	40	−8	3.47	+0.40	34.7
Stonecliffe, Ont.	489												
Ottawa, Ont.	236												
Kingston, Ont.	285	29.70	30.04	.00	23.1	+5.3	29.3	17.0	42	−1	3.03	+0.49	24.8
Toronto, Ont.	379	29.50	30.02	−.02	27.0	+5.5	32.9	21.1	47	8	2.04	−0.57	16.8
Cochrane, Ont.	930				6.3		17.3	−4.6	36	−30			
White River, Ont.	1,244	28.62	30.00	−.02	7.3	+7.1	20.5	−5.8	38	−36	1.07	−0.45	10.7
Port Stanley, Ont.	592												
Southampton, Ont.	656	29.27	30.01	−.01	24.2	+4.3	30.6	17.8	44	−2	1.70	−1.20	18.2
Parry Sound, Ont.	688	29.29	30.02	+.01	18.0	+3.7	26.5	9.6	40	−13	1.39	−1.53	13.9
Port Arthur, Ont.	644	29.31	30.05	.00	14.0	+7.6	21.5	6.6	39	−15	0.55	−0.35	4.1
Winnipeg, Man.	760												
Minnedosa, Man.	1,690	28.16	30.10	+.01	3.4	+6.1	12.1	−5.3	38	−26	0.42	−0.19	4.2
Le Pas, Man.	860				−3.5		7.8	−14.8	40	−38	0.58		5.8
Qu'Appelle, Sask.	2,115	27.08	30.06	−.02	4.2	+4.8	13.9	−5.5	42	−34	0.60	−0.13	6.0
Medicine Hat, Alb.	2,144	27.64	30.00	−.05	15.6	+4.4	25.2	6.0	45	−36	0.49	−0.18	4.9
Moose Jaw, Sask.	1,759				7.6		16.3	−1.0	42	−33	0.36		3.6
Swift Current, Sask.	2,392	27.35	30.02	−.05	11.6	+3.6	21.9	1.4	42	−40	1.10	+0.36	11.0
Calgary, Alb.	3,428												
Banff, Alb.	4,521	25.22	29.99	+.01	16.0	−3.2	27.2	4.7	37	−30	1.79	+0.87	17.9
Edmonton, Alb.	2,150	27.59	30.00	−.02	7.6	−0.7	18.4	−3.2	44	−30	0.90	+0.23	9.0
Prince Albert, Sask.	1,450	28.46	30.14	+.05	1.7	+4.7	13.0	−9.6	41	−40	0.42	−0.27	4.2
Battleford, Sask.	1,592	28.29	30.15	+.06	0.9	+0.8	9.8	−8.0	38	−31	0.15	−0.22	1.5
Kamloops, B. C.	1,262												
Victoria, B. C.	230	29.62	29.88	−.12	42.9	+3.4	47.8	38.0	52	31	2.51	−1.59	0.0
Barkerville, B. C.	4,180												
Triangle Island, B. C.	680												
Prince Rupert, B. C.	170												
Hamilton, Ber.	151	30.02	30.19	+.08	64.2	+2.7	71.0	57.4	75	53	2.70	−1.74	0.0

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Barkerville, B. C.	4,180	25.57	30.03	+.14	12.6	−5.2	19.6	5.6	39	−23	3.47	+0.87	34.7

Chart I. Tracks of Centers of Anticyclones, February, 1927. (Inset) Departure of Monthly Mean Pressure from Normal
(Plotted by Wilfred P. Day)

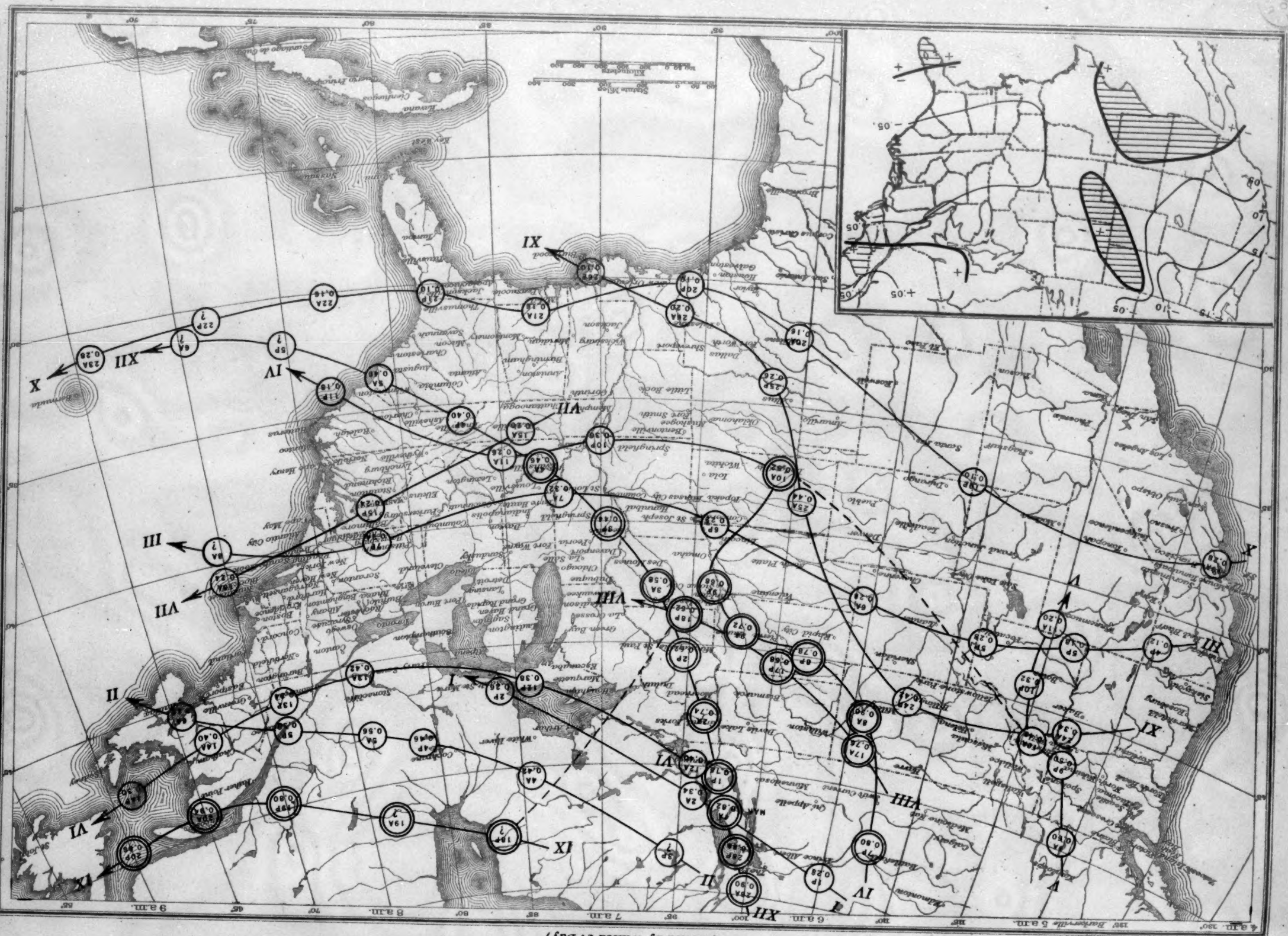

Chart I. Tracks of Centers of Anticyclones, February, 1927. (Inset) Departure of Monthly Mean Pressure from Normal
(Plotted by Wilfred P. Day)

Chart II. Tracks of Centers of Cyclones, February, 1927. (Inset) Change in Mean Pressure from Preceding Month

(Plotted by Wilfred P. Day)

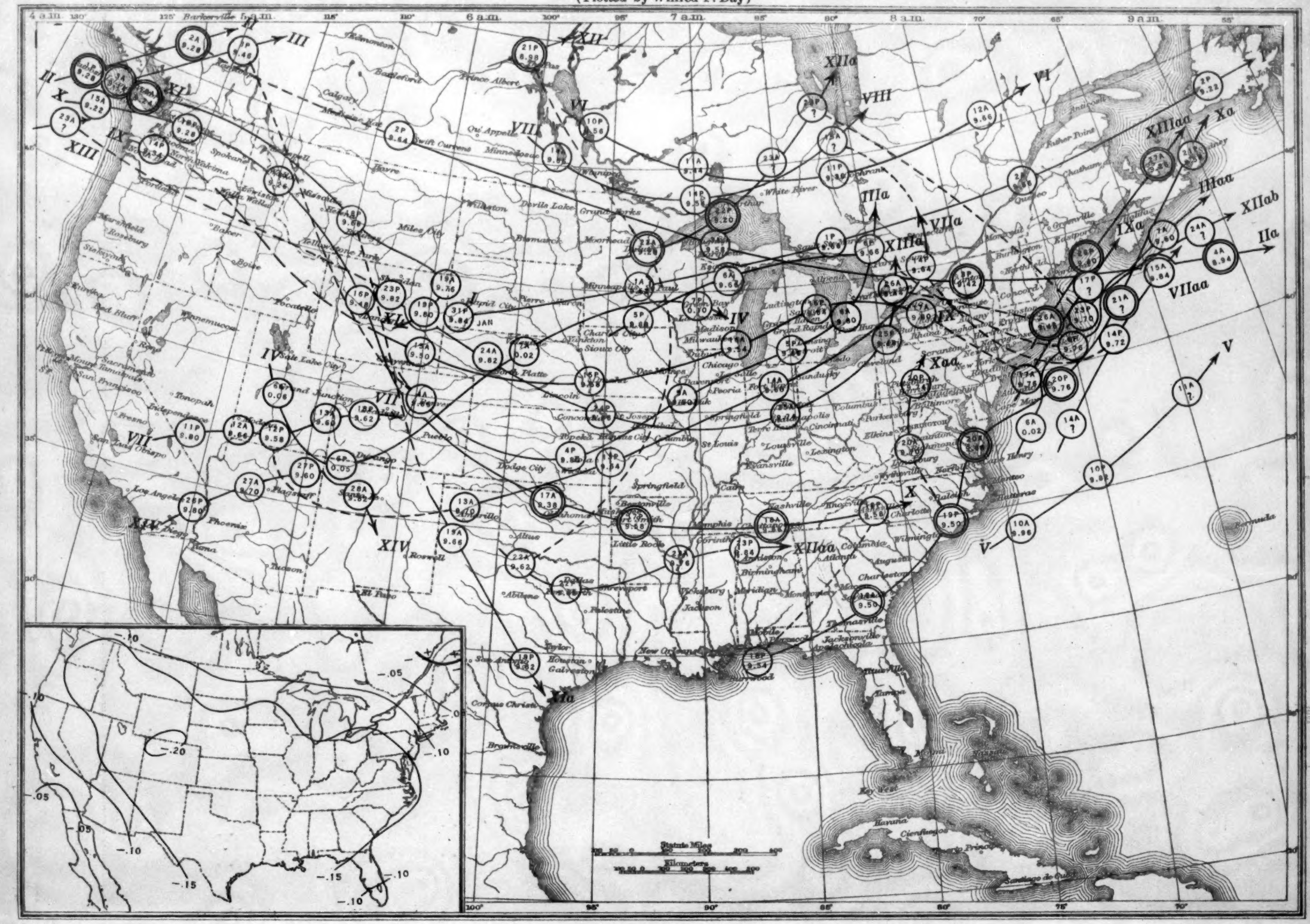

Chart III. Departure (°F.) of the Mean Temperature from the Normal, February, 1927

Chart III. Departure (°F.) of the Mean Temperature from the Normal, February, 1927

Shaded portions show excess (+).
Unshaded portions show deficiency (—).
Lines show amount of excess or deficiency.

Chart IV. Total Precipitation, Inches, February, 1927. (Inset) Departure of Precipitation from Normal

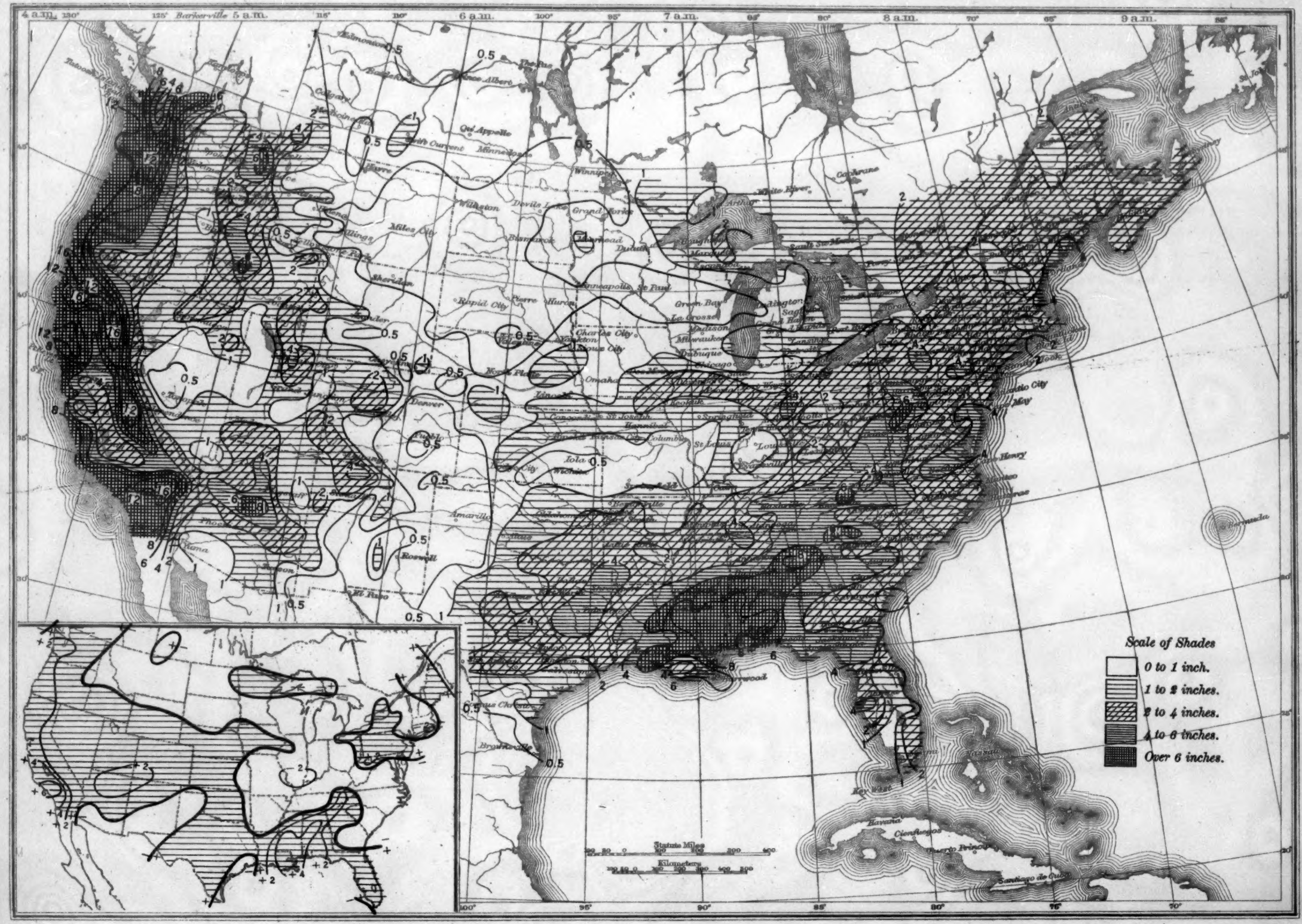

Chart V. Percentage of Clear Sky between Sunrise and Sunset, February, 1927

Chart V. Percentage of Clear Sky between Sunrise and Sunset, February, 1927

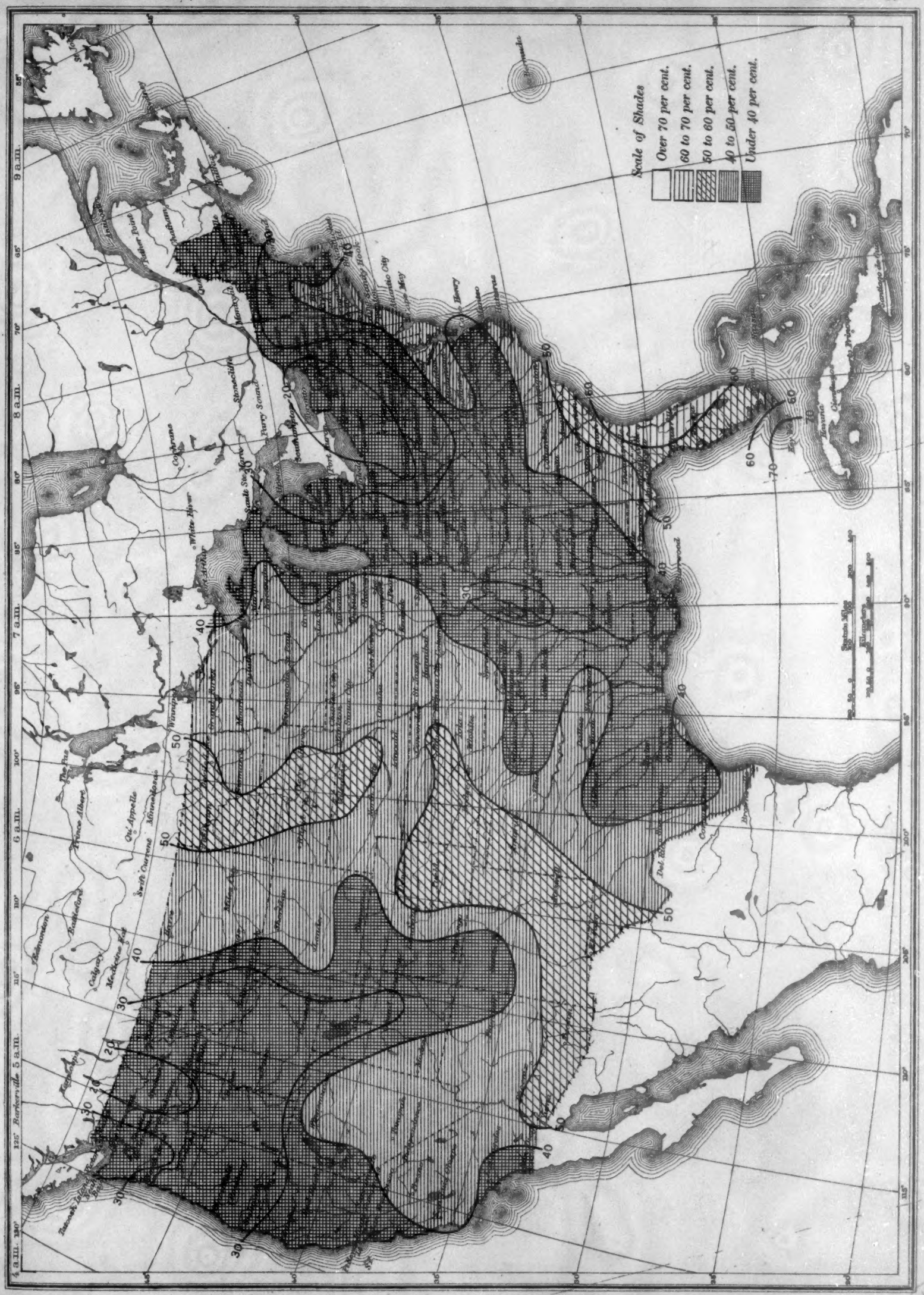

Chart VI. Isobars at Sea level and Isotherms at Surface; Prevailing Winds, February, 1927

Chart VII. Total Snowfall, Inches, February, 1927. (Inset) Depth of Snow on Ground at end of Month

Chart VII. Total Snowfall, Inches, February, 1927. (Inset) Depth of Snow on Ground at end of Month

Chart VIII. Weather Map of North Atlantic Ocean, February 3, 1927

Chart VIII. Weather Map of North Atlantic Ocean, February 3, 1927

(Plotted by F. A. Young)

Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
○ clear, ◑ partly cloudy, ● cloudy,
• rain, ▲ hail or sleet, ✳ snow,
═ fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

Arctic Circle

Tropic of Cancer

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Chart IX. Weather Map of North Atlantic Ocean, February 4, 1927

(Plotted by F. A. Young)

Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
○ clear, ◑ partly cloudy, ● cloudy,
• rain, ▲ hail or sleet, ✳ snow,
═ fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

Arctic Circle
Tropic of Cancer
Bermuda
Hatteras
Key West
Nassau
Turks Island
Santo Domingo
Kingston
Isle of Pines
Swan I.
Pinar del Rio
Progreso
Isabela
Camaguey
Charleston
Jacksonville
Charlotte
Lynchburg
Galveston
Brownsville
Del Rio
Dallas
Fort Smith
Wichita
Amarillo
Denver
Omaha
Duluth
Chicago
Cleveland
Cairo
Lexington
Keokuk
Cochrane
White River
Stonecliffe
Quebec
Father Point
Harrington
Chatham
Yarmouth
Boston
New York
Oswego
Atlantic City
Atlanta
Montgomery
Meridian
Vicksburg
Memphis
Little Rock
Shreveport
Abilene
Roswell
Santa Fe
Pueblo
Salt Lake City
Winnemucca
Roseburg
Portland
Tatoosh I.
Prince Rupert
Edmonton
Medicine Hat
Prince Albert
Qu'Appelle
Winnipeg
Moorehead
Duluth
Sydney
Louisburg
Scatarie I.
Belle Isle
Cape Race
Flores
Horta
Lisbon
Funchal
Gibraltar
Tangier
Malta
Valentia
Blacksod Pt.
Malin Head
Stornoway
Thorshavn
Lerwick
Kirkwall
London
Paris
Perpignan
Rome
Scilly
Scotlandford

29.7 29.8 29.9 30.0 30.1 30.2 30.3 30.4 30.5 29.6 29.5 29.4 29.3 29.2 29.1 29.0 28.9 28.8 28.7 28.6 28.5 28.4 30.0 30.1 30.2 30.3 30.4 30.1

February, 1927. M. W. R.

Chart X. Weather Map of North Atlantic Ocean, February 5, 1927

Chart X. Weather Map of North Atlantic Ocean, February 5, 1927

(Plotted by F. A. Young)

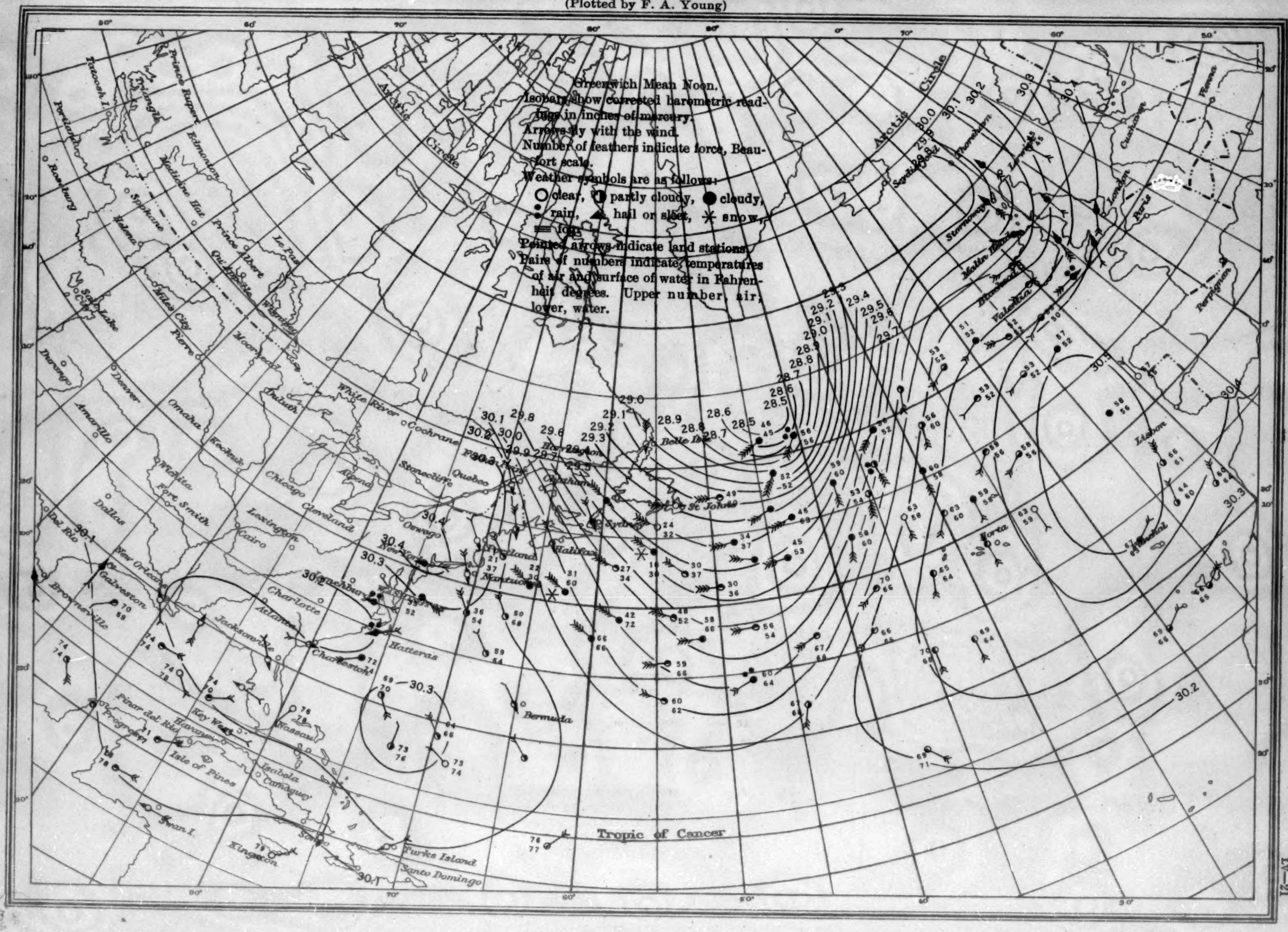

Chart XI. Weather Map of North Atlantic Ocean, February 6, 1927

(Plotted by F. A. Young)

Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
○ clear, ◑ partly cloudy, ● cloudy, • rain, ▲ hail or sleet, ✳ snow, ≡ fog.
Pointed arrows indicate land stations.
Pairs of numbers indicate temperatures of air and surface of water in Fahrenheit degrees. Upper number, air; lower, water.

Tropic of Cancer